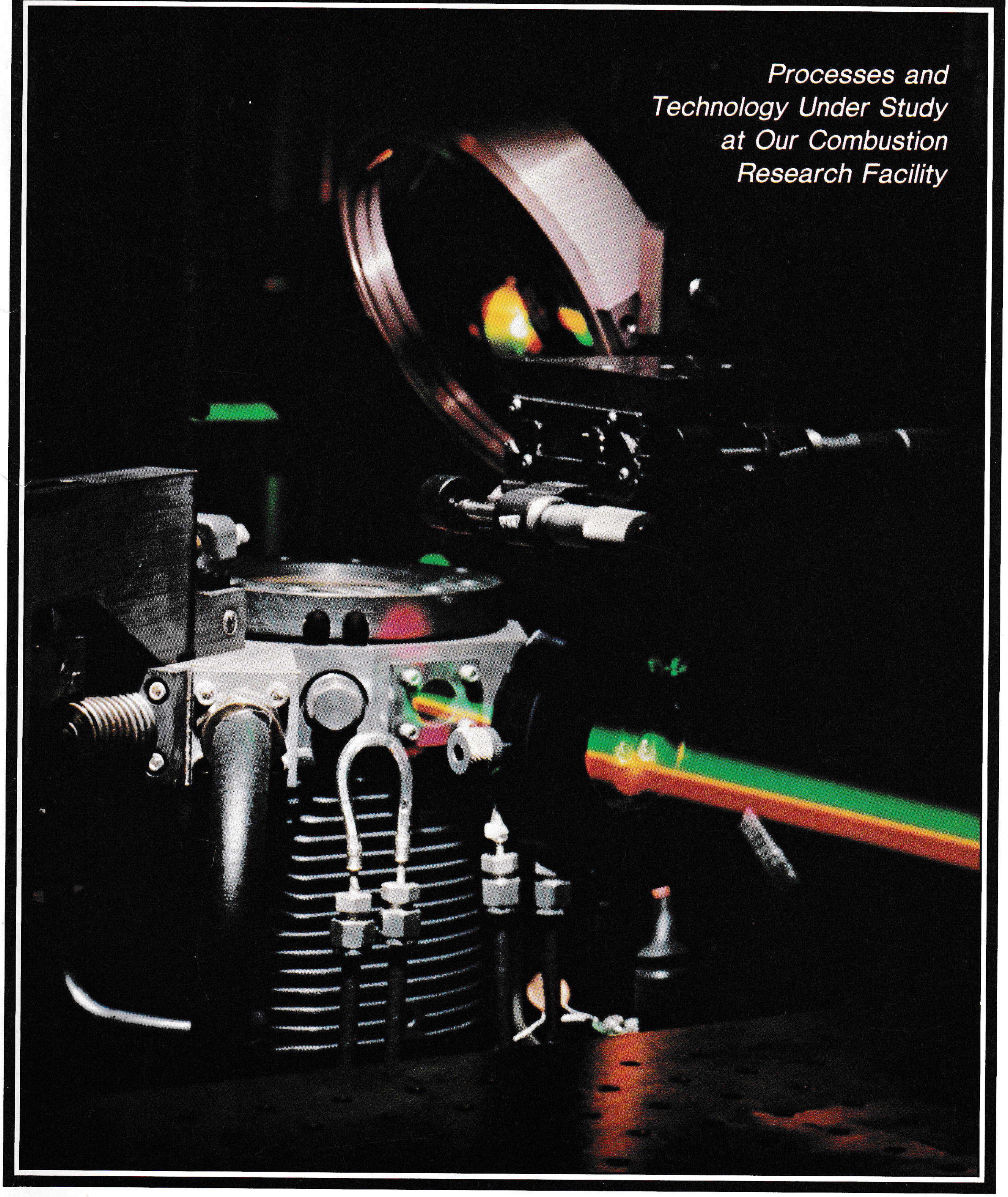
SANDIA TECHNOLOGY

Sandia National Laboratories, Albuquerque, New Mexico/Livermore, California/Tonopah, Nevada • June 1982



Processes and Technology Under Study at Our Combustion Research Facility

W. J. (Jack) Howard, Executive Vice President of Sandia National Laboratories, retired March 31 after nearly 36 years with the Labs.

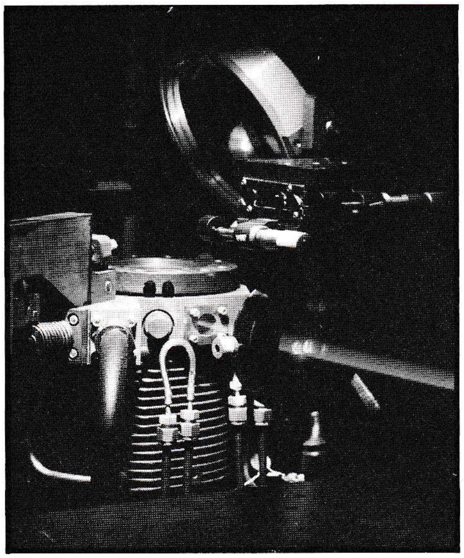
Jack joined Sandia in 1946. In 1956 he became Sandia's first Manager at Livermore, and later in that year, when the organization had grown, was promoted to Director of Systems Development there.

From December 1963 to June 1966 he was at the Pentagon, where he was assistant to the Secretary of Defense for Atomic Energy, as well as Chairman of the Department of Defense's Military Liaison Committee to the Atomic Energy Commission. As a result of this work, he was awarded the Distinguished Public Service Medal by Defense Secretary Robert McNamara.

In 1966 he returned to Sandia at Albuquerque as Director of Advanced Systems Development, and later that year became Vice President of Components and Systems. He became the Executive Vice President of the Laboratories and a member of the Board of Directors in 1973.

In 1976 he was a delegate to the Strategic Arms Limitation Talks in Geneva.

Jack remains a member of the Advisory Committee to the Defense Intelligence Agency, and will continue as a consultant for Sandia National Laboratories. He also retains membership on the General Engineering Peer Committee of the National Academy of Engineering, to which he was elected in 1979.



In cover photo, temperatures and concentrations of combustion products inside an auto engine are measured with high precision and resolution by coherent anti-Stokes Raman spectroscopy. A resident staff of 60 at Sandia's Combustion Research Facility works with university and industry counterparts to extend knowledge of fundamental combustion processes and improve combustion technology.

Article begins on page 2.

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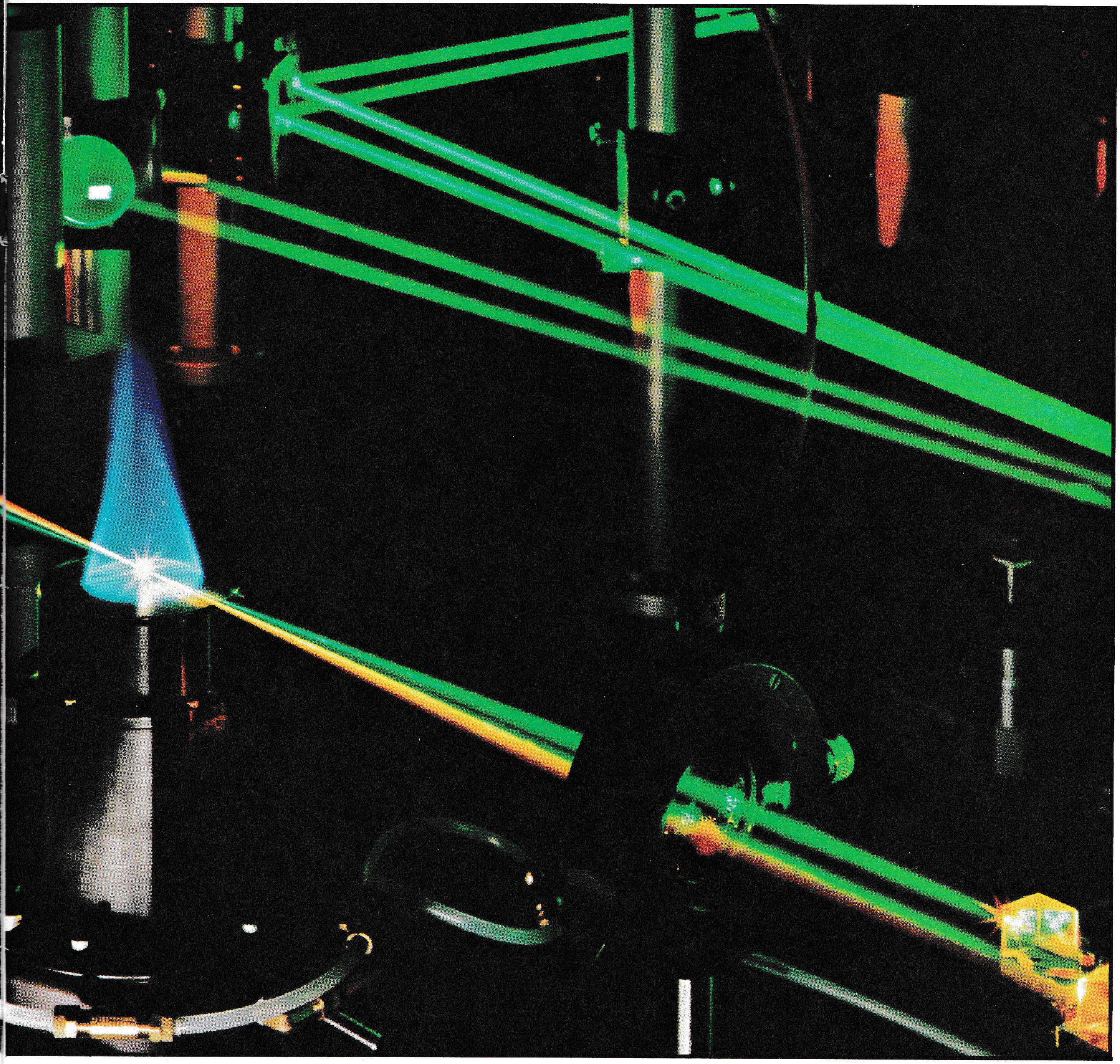
Sandia National Laboratories
Albuquerque, New Mexico/Livermore, California/Tonopah, Nevada
Sandia National Laboratories is a multiprogram laboratory operated for the United States Department of Energy, with major facilities at Albuquerque, NM, and Livermore, CA, and a test range at Tonopah, NV. Our primary responsibilities are research and development for nuclear weapon systems. Substantial efforts are also applied to energy research and other programs of national importance. This publication describes some of our activities and accomplishments in unclassified programs. Activities of a classified nature are reported in a companion publication, ***Sandia Weapon Review.***

Typical of our advanced diagnostics development effort is this application of coherent anti-Stokes Raman spectroscopy in which a single red, and two green, laser beams are focused to intersect in a flame. At the point of convergence, the high-optical-power-density beams induce molecules in the flame to produce a faint beam of blue light (not visible here), which comes out of the flame to the right. This blue light signal, which is characteristic of the type of molecule present, is used to measure the gas temperature as well as the concentrations of molecules (such as carbon monoxide).

Combustion Research Aimed At Greater Efficiency

Researchers at the national Combustion Research Facility are investigating combustion processes in flames, coal combustors, and internal combustion engines. Increased efficiency in these processes will help make the US energy-independent and at the same time improve the quality of our environment.



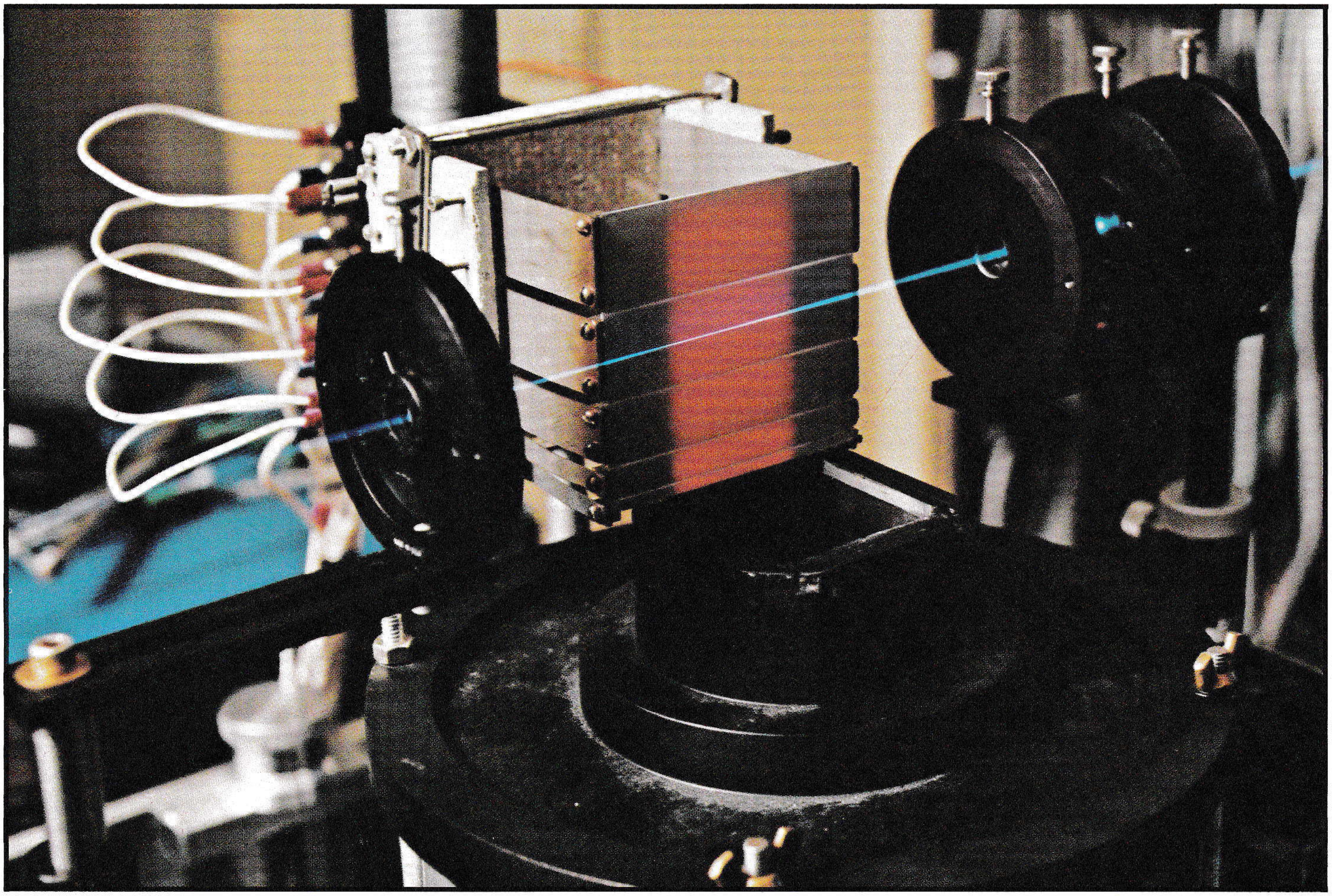
Our Combustion Research Facility, dedicated in March 1981 at the Livermore laboratory, is a national research center devoted to understanding fundamental combustion processes and to devising diagnostic tools and research techniques to advance combustion technology. The facility houses specially designed centralized laser systems for diagnostic application and advanced computers for analysis. These capabilities and the facility's research laboratories are available to scientists from the general combustion research community.

The Combustion Research Facility melds the strengths of a fundamental research program with applied research projects in engines and coal combustors. A resident staff of 60 scientists and engineers works with engineers and scientists from industry and from universities, thus guaranteeing the widespread and rapid transfer of the scientific results.

Fundamental Combustion Studies

In our fundamental flame research, supported by the Department of Energy (DOE) Office of Basic Energy Sciences, we are improving our understanding of how fluid mechanics and chemical kinetic processes influence combustion. Simple flames provide test beds for developing diagnostic tools. Detailed studies are underway on turbulent reacting flows, droplet combustion, and the mechanisms responsible for forming pollutants such as soot and oxides of nitrogen. For these studies, we have developed a variety of combustion environments—from laminar premixed flames to isolate the effects of chemical kinetics from those of transport processes (such as heat conduction and fluid flow), to turbulent diffusion flames for the study of diffusive transport processes.

Before we can significantly improve efficiency and cleanness of combustion devices and their ability to burn alternative fuels, we need fundamental knowledge about combustion. This knowledge was largely inaccessible before the development of advanced laser probes for measuring and computers for modeling and data management. With laser-induced fluorescence techniques, for example, we can determine with high precision and high spatial resolution the temperature and radical species concentrations in a combustion boundary layer. In this photo, a lean mixture of hydrogen and air flows across an electrically heated platinum plate while the boundary layer is probed with a blue (argon ion) laser beam.

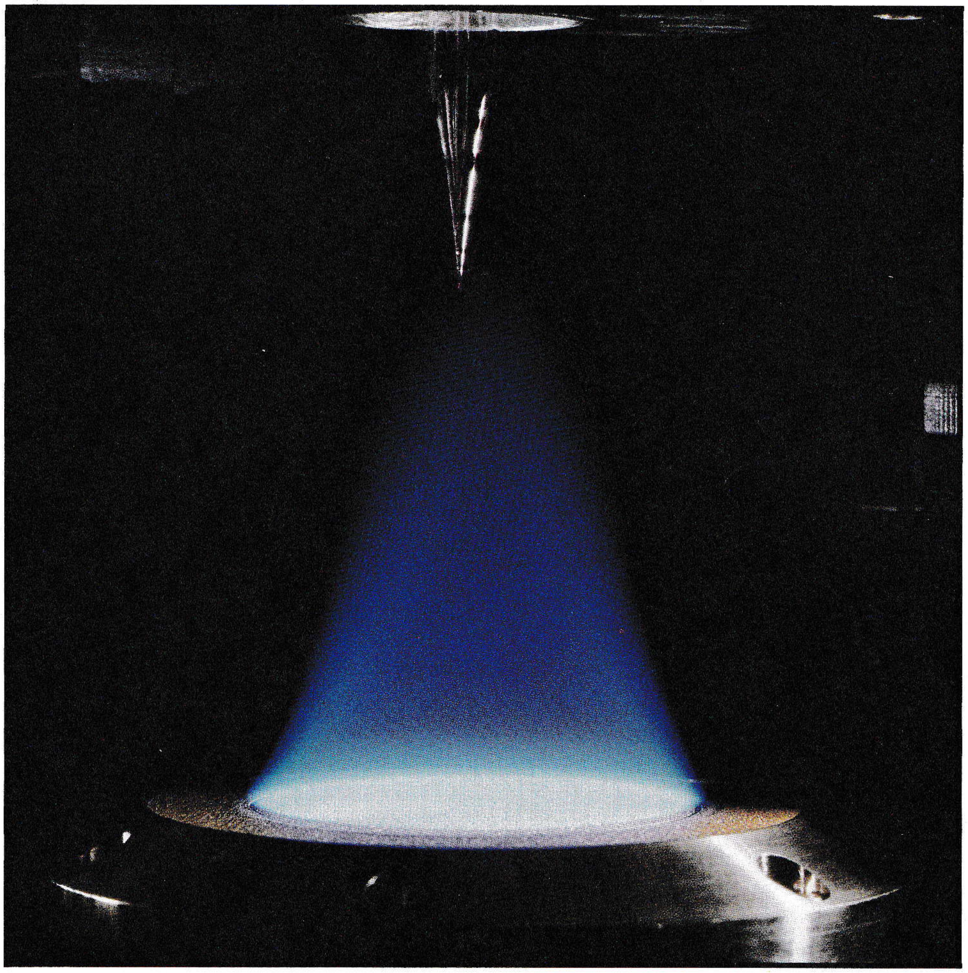


Nonintrusive optical probes are used in the flame research programs to obtain spatially and temporally resolved data on species concentrations, temperature distributions, and velocity fields in simple flames, laboratory engines, and combustors. The effort is of two kinds. We evaluate conventional laser diagnostics such as laser Doppler velocimetry, elastic (Rayleigh) laser scattering, and inelastic (spontaneous Raman) scattering. We also apply and improve new diagnostic techniques such as nonlinear Raman scattering, spatially resolved infrared absorption spectroscopy, and laser fluorescence spectroscopy. These new techniques provide relatively strong signals and high background rejection. With pulsed- and crossed-beam laser configurations, we can achieve increased spatial and temporal resolution in reacting systems.

Closely coupled with ongoing experimental research programs are the computational efforts. The goals here are to aid in the interpretation of experimental results, and to provide a predictive capability—a framework for extrapolating from fundamental experimental results to improvements for practical combustion devices.

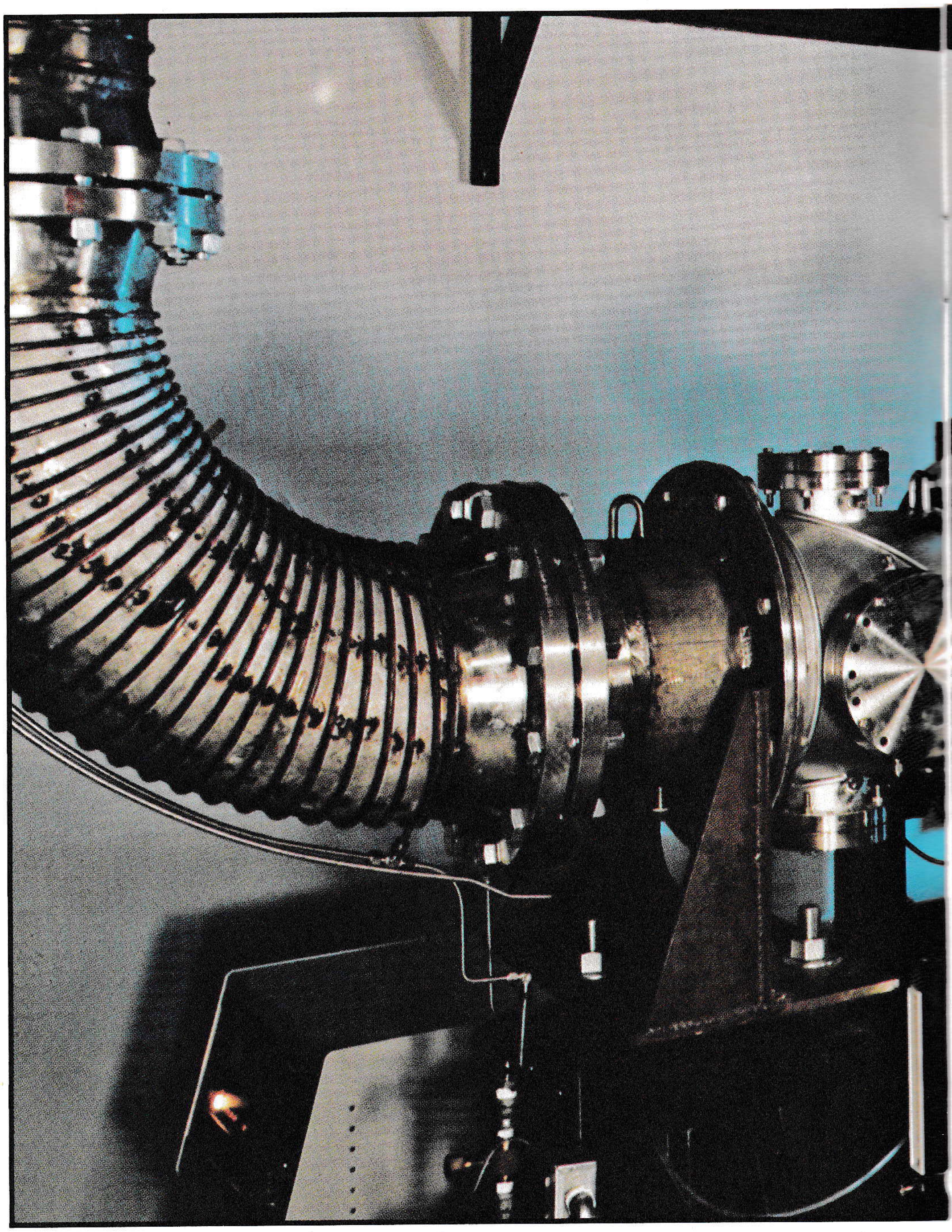
Fossil Energy Research

Fossil fuel studies are supported by the DOE's Fossil Energy Division in the Office of Coal Utilization. These studies focus on the fundamentals of coal combustion and on basic research, development, and industrial applications of advanced diagnostics and instrumentation. In the fundamental research work, we are acquiring knowledge and improving our understanding of the



We are testing an idea for a flame-sampling probe intended to capture and analyze highly reactive chemical compounds (free radicals) present in flames. Those species are difficult to analyze by conventional means because they are highly unstable and analytic methods are time-consuming. In this apparatus, flame gases are drawn into the sampling probe (the conical glass projection pointing downward) by a conventional vacuum pump system. Once inside the probe, the gases are allowed to react chemically with a special additive such as deuterium. A scavenging reaction with the additive converts unstable compounds to stable ones which can then be analyzed by conventional mass spectrometry.

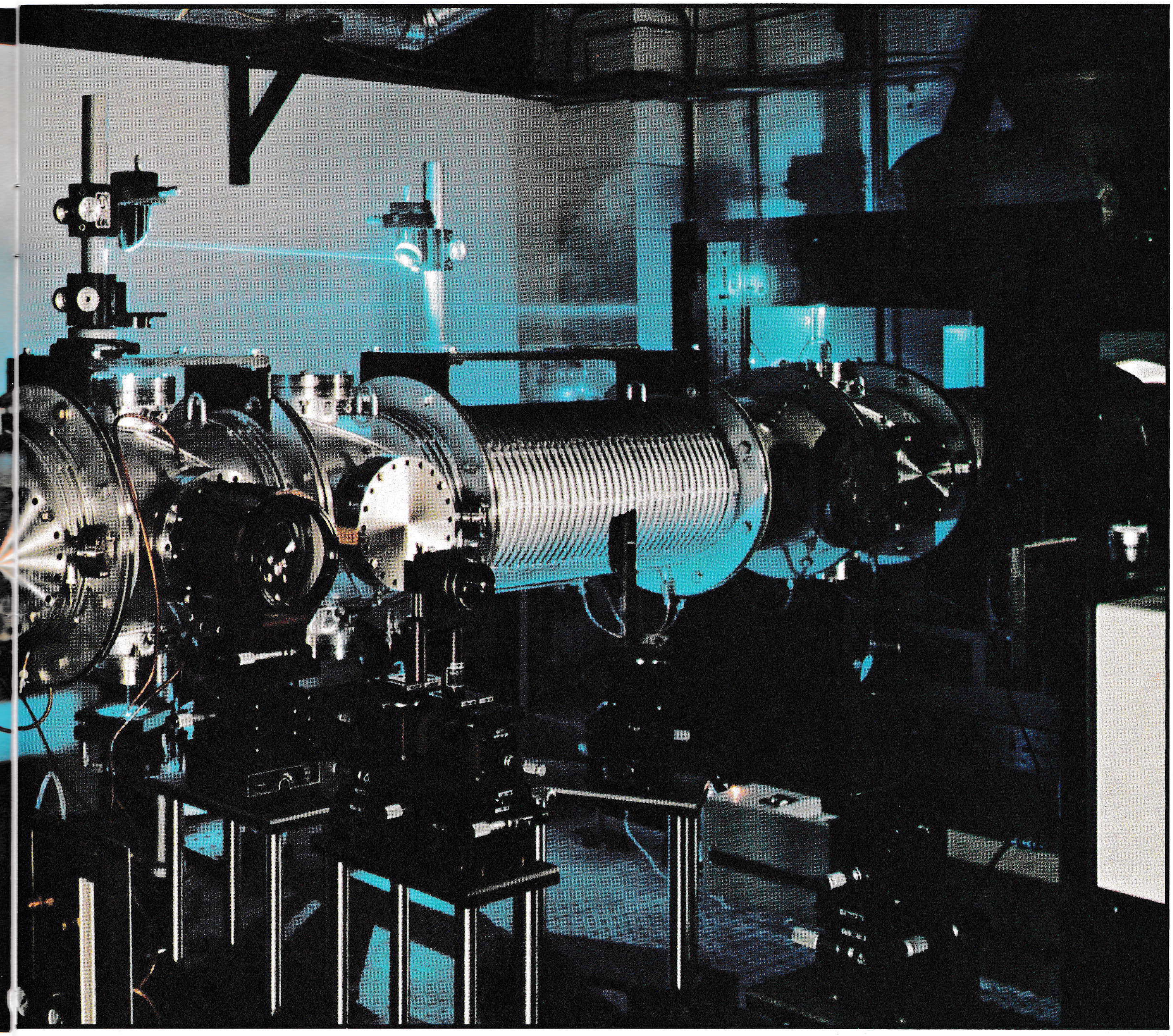
This atmospheric combustion-exhaust simulator provides a controlled, high-temperature (1200°C) variable-flow-rate (0.127 to 2.54 m/s) exhaust gas stream in which a variety of materials can be corrosion-tested. The device produces a realistic environment in which trace species or particulates typical of combustion processes can be introduced into the gas stream. Sample chambers with optical access permit laser diagnostics to be used to study the chemistry of surfaces and gases. This research is vital, since future gas turbines will be designed to operate at higher temperatures and to use lower-quality fuels derived from coal. Contaminants in these fuels, particularly at high temperatures, catastrophically attack materials presently available for combustor construction.



rates and mechanisms, both chemical and physical, of pulverized coal combustion. Our aim is to contribute to practical combustion modifications and new processes which will reduce to a minimum the fouling, slagging, and polluting caused by burning coal and coal-derived fuels.

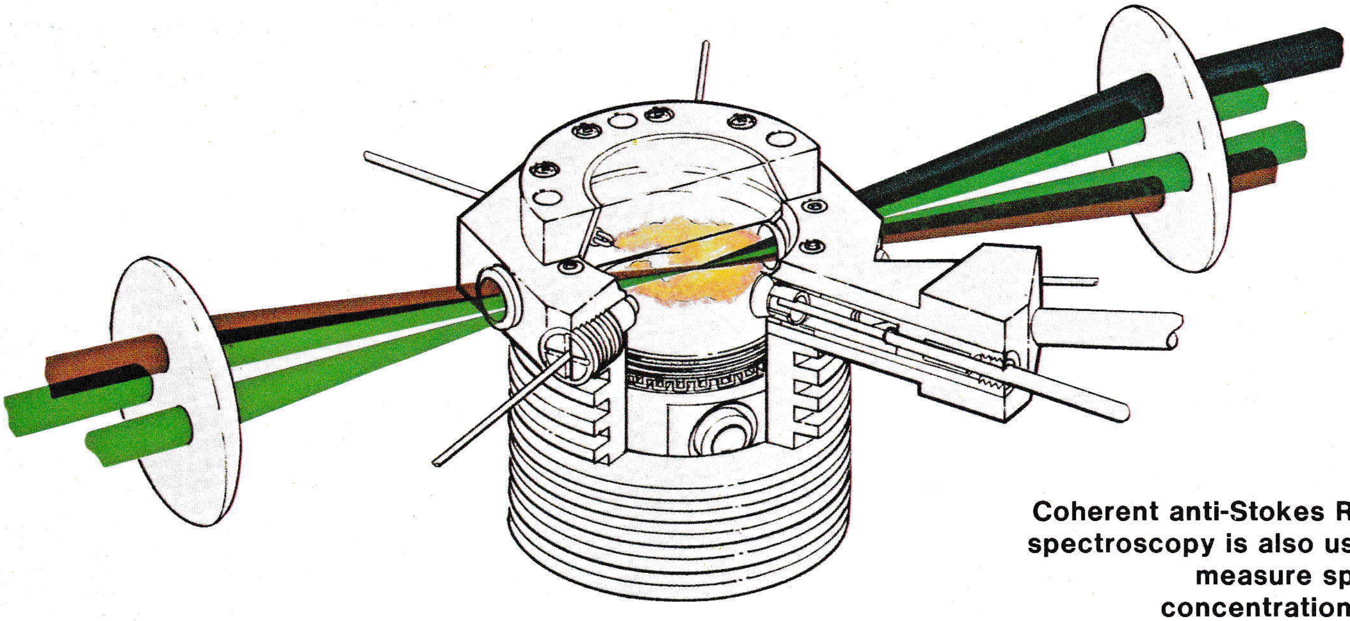
We are currently studying coal combustion parameters that govern the conversion of sulphur, fuel-bound nitrogen, and mineral matter to pollutants and other undesirable products. For the first time, the rapid processes of ignition and devolatilization followed by char oxidation can be examined in detail by simultaneously applying optical and physical probes. This basic work also includes the first application of Fourier-transform infrared spectroscopy to measure in-situ the gas temperature, to identify light gas species, and to define the aliphatic and aromatic hydrocarbons in a combustion environment.

Diagnostic activities include fundamental research and laboratory development of advanced optical methods—principally, those based on lasers. The objective is to measure the properties of particle-laden combustion zones, gasification zones, and process streams. A major effort is aimed at developing integrated techniques to simultaneously detect the size, number density, velocity (flux), temperature, and material

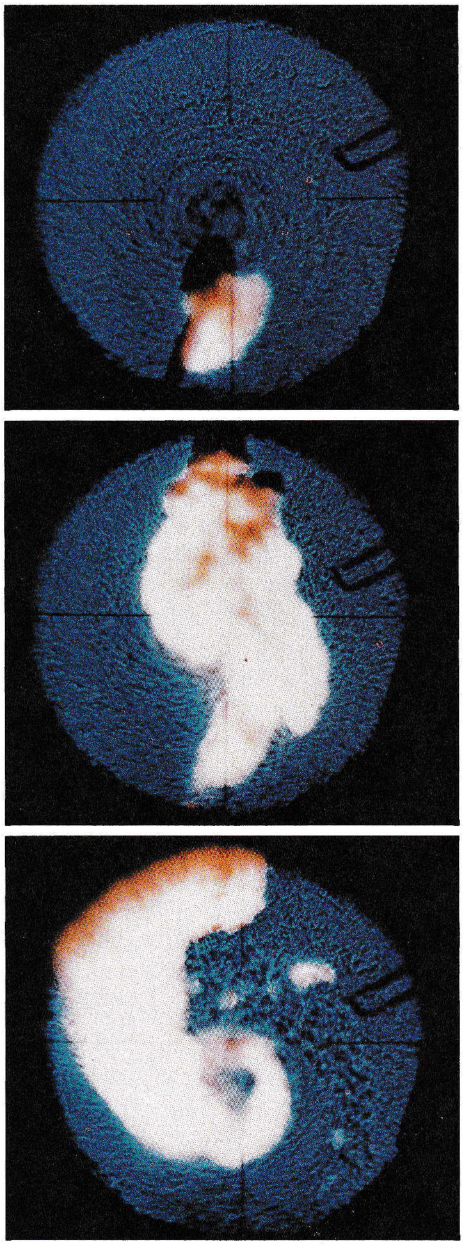


properties of fuel droplets and of coal, ash, and soot particles. A significant, and successful, effort has also been devoted to developing novel sampling methods for measuring in real time and at high temperatures and pressures the size distribution and mass of particles entrained in process streams. For this purpose, we have invented and applied for a patent on a continuous, real-time particle mass monitor.

In addition, optical methods are being developed for real-time, simultaneous detection of gas species concentrations and temperatures in particle-laden combustion environments. Fundamental to these efforts is the application of several laboratory combustion simulators. These devices permit researchers to evaluate and calibrate each diagnostic tool in realistic particle-laden flows. We have installed a number of such optical and physical sampling instruments in actual flow conditions at industrial sites to test their ability to detect particles as small as one-tenth micron in diameter.



Coherent anti-Stokes Raman spectroscopy is also used to measure species concentrations and temperature in practical combustors such as engines. Above and at right, as the injected mixture is ignited at the spark-plug electrode and the flame propagates throughout the cylinder, temperatures and concentrations of combustion products are measured with high precision and resolution.

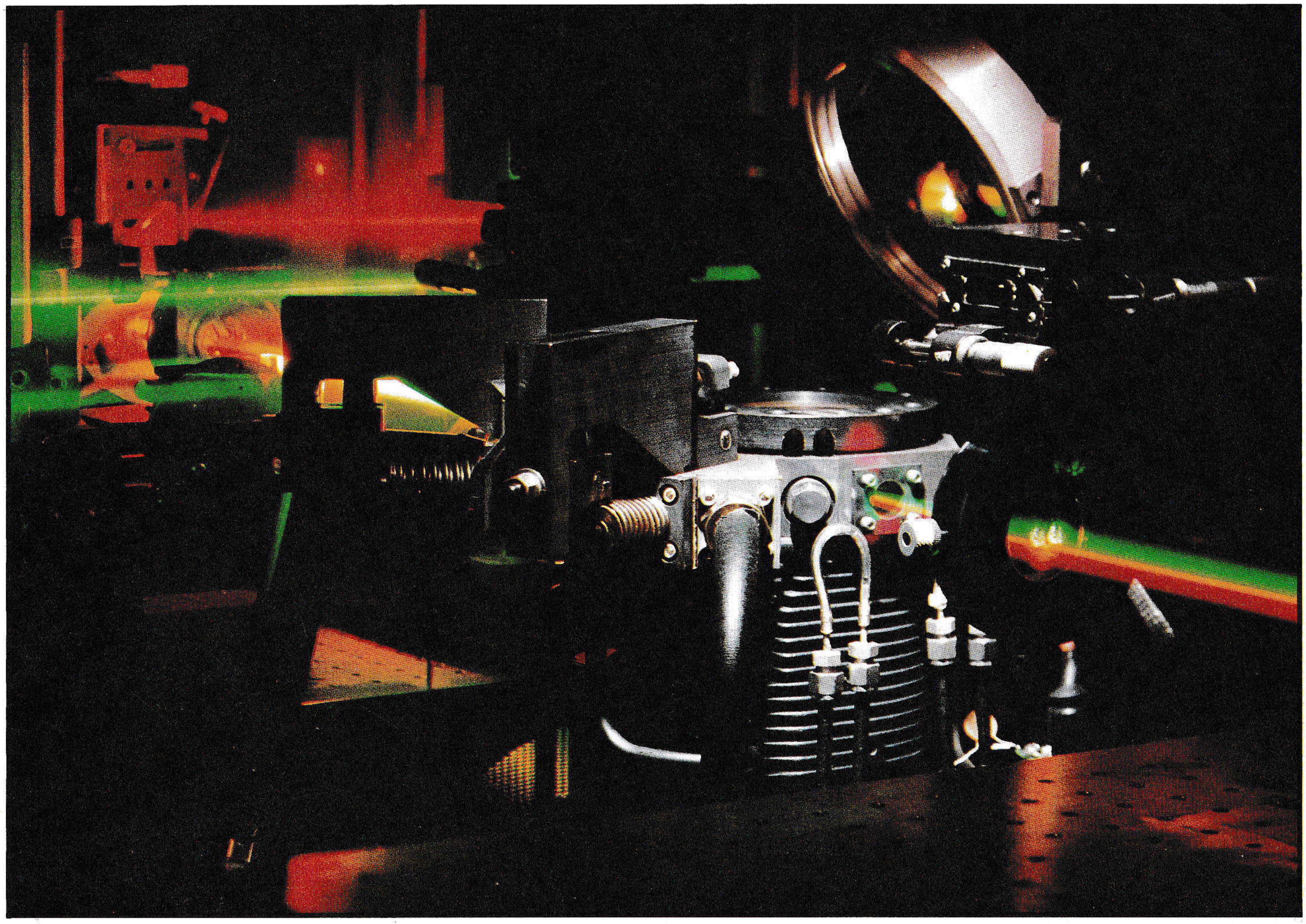


Research has contributed to the development of advanced laser-based techniques for in-situ, time- and space-resolved measurements of temperature, velocity, and species concentrations. These frames from a high-speed laser shadowgraph film show the burning of diesel fuel spray injected into 1300°C, lean hydrogen/air combustion products at 30 atmospheres pressure. The luminous emission is from particulates formed in the rich spray flame. Since they are expelled into the environment, these particulates are a cause for much concern as the use of diesel engines becomes more widespread. Top photo taken 1 ms after injection, middle view at 3 ms, and bottom photo at 7 ms.

Internal-Combustion Engine Studies

In these studies, supported by the DOE Division of Energy Conversion and Utilization Technology under the Assistant Secretary for Conservation and Renewable Energy, we use many of the techniques developed in our fundamental research to study critical problems in three basic engine types: dilute homogeneous-charge spark ignition, direct-injection stratified-charge spark ignition, and diesel.

Working with all US automakers, we are developing information on a variety of problems in fuel-spray mixing, soot formation, and flame propagation. Nonperturbing, laser-based diagnostics applied inside functioning laboratory engines have given us new understanding of combustion in these environments.



We have shown that both the pre- and post-ignition behavior of gases can be accurately characterized by Raman spectroscopy and laser Doppler velocimetry, and that flame speed and thickness can be measured by observation of Rayleigh scattering. We also use other laser-based techniques to measure particulate concentrations.

Engine programs involve interaction with universities, other national laboratories, the auto industry, and the Motor Vehicle Manufacturers Association. We represent the United States on the Combustion Project of the International Energy Agency, and are also involved in a number of cooperative engine studies. Working with General Motors, Princeton, and Los Alamos and Lawrence Livermore national laboratories, we are studying spray mixing and flame propagation in direct-injection stratified-charge engines. A second study on ignition, knock, and quenching in dilute homogeneous-charge engines is underway with Ford, Exxon, the University of California-Berkeley, MIT, and Science Applications, Inc. A third study, focused on soot formation in diesel engines, involves Cummins, Chrysler, International Harvester, Los Alamos, and Systems Science and Software.

The cooperative nature of these programs ensures that the research will promptly be made available to industry. The results of our engine experiments, coupled with new computer models which predict combustion behavior, are already being used by industry designers.

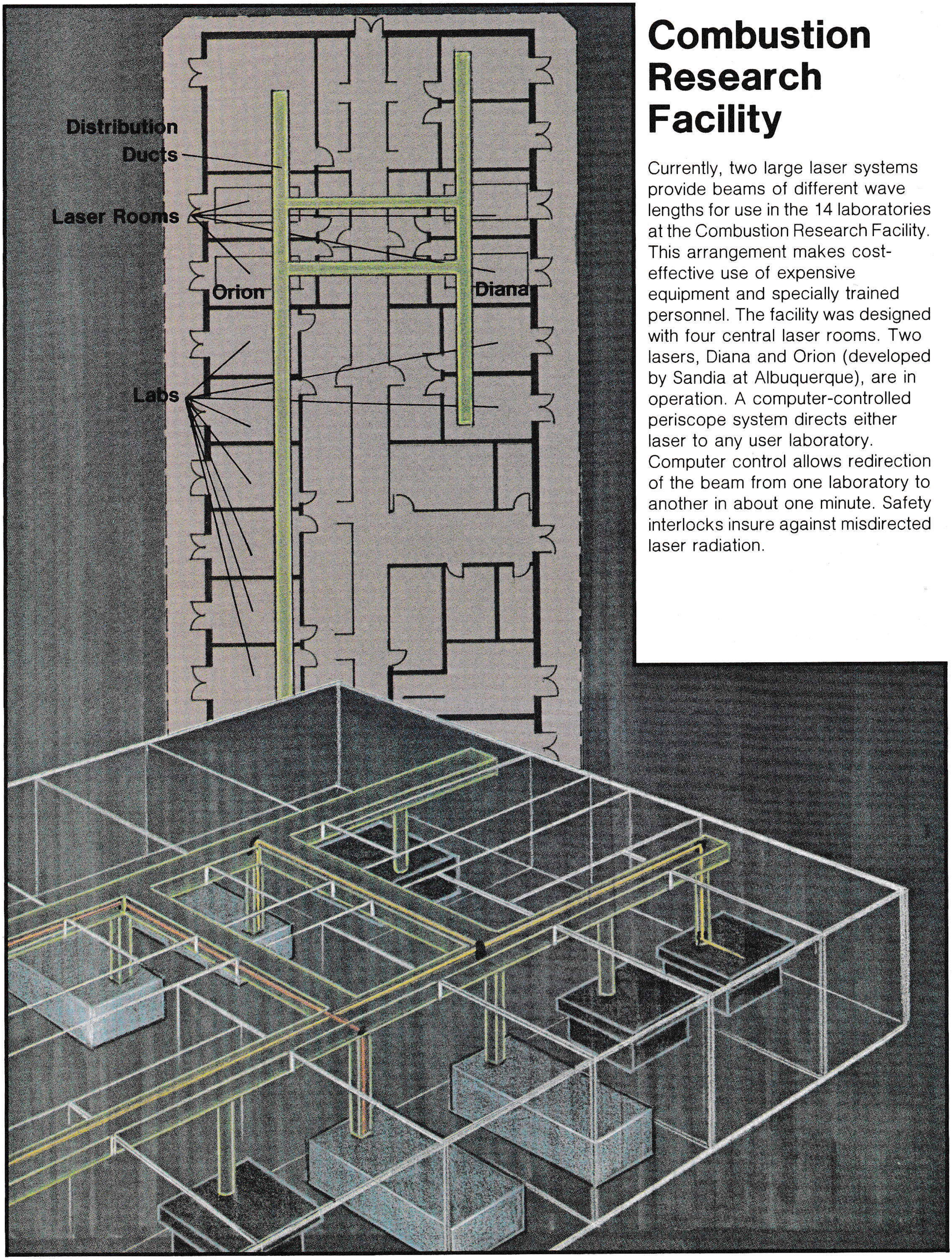
For The Future

Since over 90 percent of the energy needed to maintain US industry and commerce comes from the combustion of fossil fuels, the importance and urgency of combustion research is easily understood. Technological advances in combustion science will have a direct influence on our ability to adapt available resources to meet demands, to reduce our dependence on foreign oil, and to preserve and possibly improve the quality of our environment.

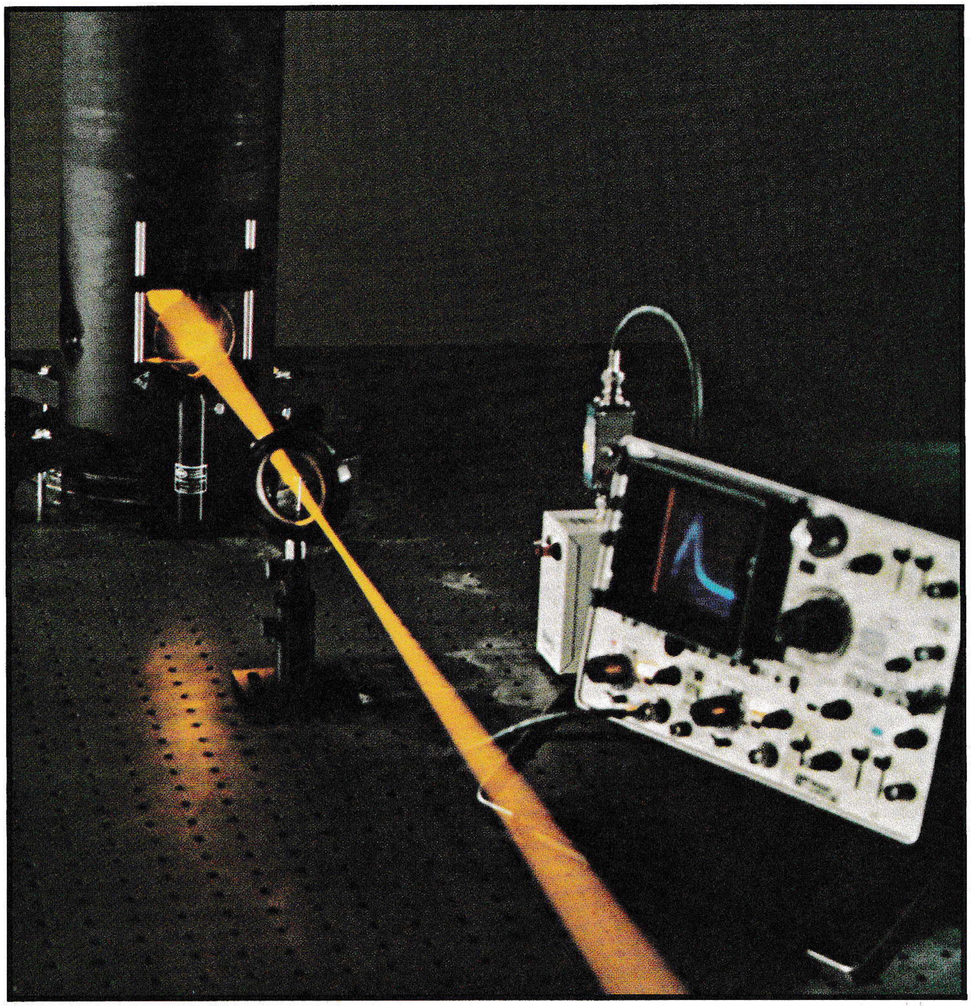
Research at the Combustion Research Facility has already established a framework for solution of the host of energy problems sure to arise in a variety of fields, including synfuels and coal-derived liquids — energy sources which are dirtier, harder to burn, and more difficult to adapt to changing needs and demands than are our current sources.

Combustion Research Facility

Currently, two large laser systems provide beams of different wave lengths for use in the 14 laboratories at the Combustion Research Facility. This arrangement makes cost-effective use of expensive equipment and specially trained personnel. The facility was designed with four central laser rooms. Two lasers, Diana and Orion (developed by Sandia at Albuquerque), are in operation. A computer-controlled periscope system directs either laser to any user laboratory. Computer control allows redirection of the beam from one laboratory to another in about one minute. Safety interlocks insure against misdirected laser radiation.



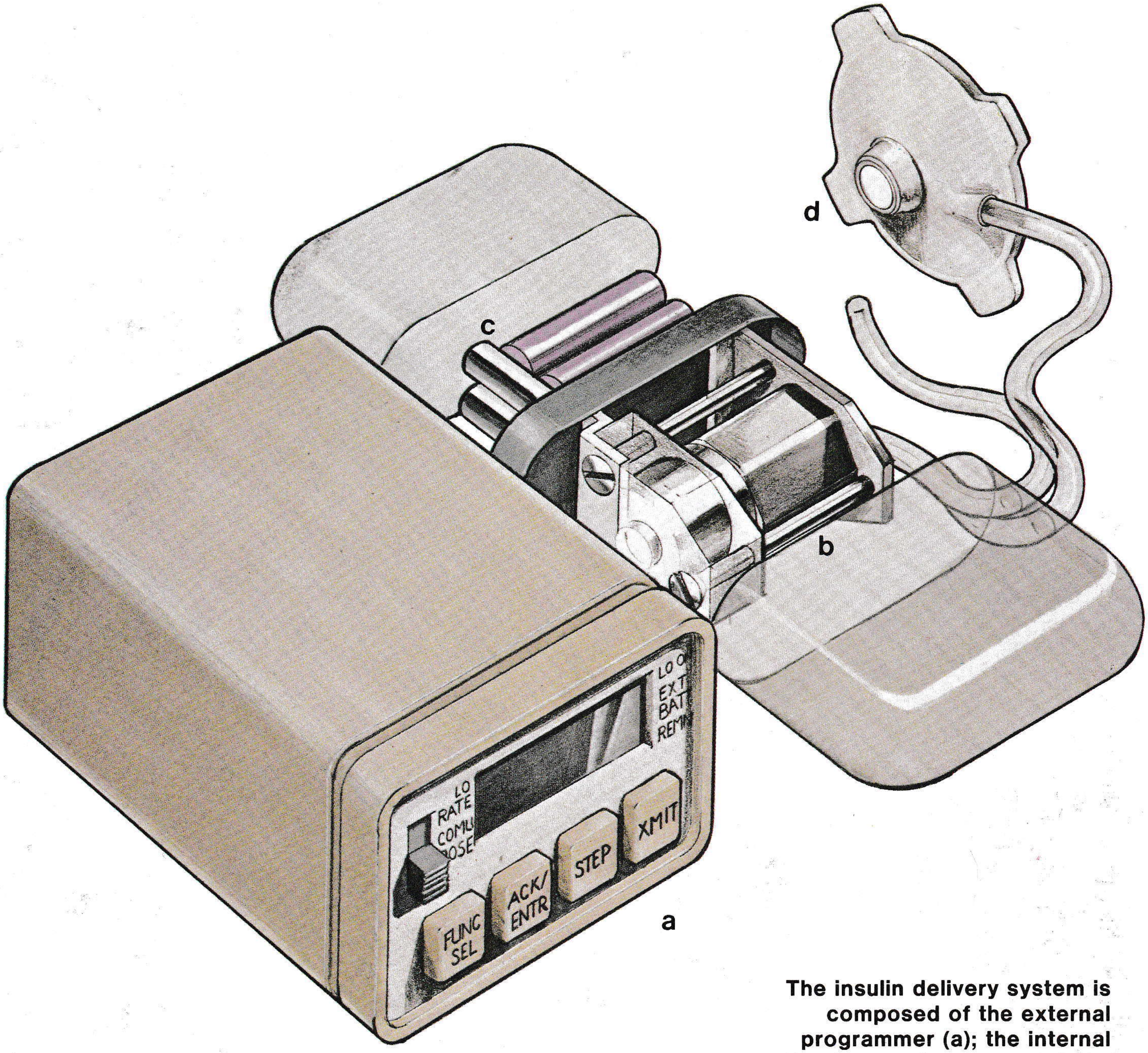
Laser beams can be directed into any one of 14 laboratories by periscope.



The Combustion Research Facility is a national research center devoted to understanding fundamental combustion and to devising diagnostic tools and research techniques to advance combustion technology.

For additional information, call Dan Hartley at (415) 422-2747.

Implantable Insulin Delivery System


d
c
b
LO
EXT
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RATE
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OSE
XMIT
STEP
ACK/ ENTR
FUNC SEL
a

The insulin delivery system is composed of the external programmer (a); the internal titanium enclosure containing the pump (b), electronic controls, and the power supply (c); and the insulin reservoir (d). Insulin is delivered to the peritoneal cavity by a catheter.

An electronically controlled insulin pump, derived from weapon technology, has provided reliable insulin delivery when implanted in diabetic patients. Convenient and simple for the patient to use, the device may substantially reduce the long-term complications of diabetes through better control of blood glucose.

The first electronically controlled, remotely programmable system that simulates the insulin delivery function of the human pancreas was implanted in a diabetic patient by physicians at the University of New Mexico (UNM) School of Medicine in January 1981. Based largely on the success of this implant over a one-year period, similar implants were performed on two additional patients on January 13, 1982.

The implantable insulin pumping system was developed jointly by Sandia and the UNM School of Medicine. It was preceded by an external insulin pump developed earlier by these institutions. Working closely with the UNM medical staff, we provided the research, engineering, and fabrication of the pumps and their associated controls. All medical, clinical, and surgical work was done by UNM.

The School of Medicine began using the external pump in its diabetes research program in 1976. When the implantable system became available, it was tested in diabetic dogs. Joint development of the new system for use in humans began in 1980 with support from the National Institutes of Health.

Two requirements were particularly important in development of the insulin pump — requirements that are also critical in nuclear weapon programs: high reliability and precision control. Many other features of the insulin delivery system are also spinoffs from technologies developed originally for nuclear weapons.

The Nature of Diabetes

Diabetes is a family of diseases, all of which are characterized by a blood-sugar imbalance. In one form or another, diabetes affects about 5% of the US population. Between 1 and 2 million diabetics in the US require daily injections of insulin. Diabetes is categorized in two general types. The most common onset age for Type I (juvenile-onset) diabetes is at puberty, but it may occur at any age. The main characteristic, regardless of age, is a lack of insulin secretion. Type II (maturity-onset) diabetes is characterized by an inefficiently operating pancreas and also by tissue resistance to insulin's action in reducing blood glucose.

Insulin, discovered in 1921, is a complex protein normally secreted by the pancreas. This vital hormone is necessary for carbohydrate metabolism; when it is lacking, the result is high levels of blood glucose. Uncontrolled blood-glucose levels in juvenile-onset diabetes is a serious medical problem that, if untreated, ultimately leads to coma and death. The daily injections of insulin typically used by juvenile-onset diabetics still allow major fluctuations of the diabetic's blood glucose, with significantly high levels predominating. These high levels are an important factor in causing long-term complications such as blindness, kidney failure, and heart failure, and UNM School of Medicine's diabetes research is focused on their elimination.

The Juvenile Diabetes Association lists diabetes as the third leading cause of death in the US. Diabetes, usually of many years duration, may be accompanied by thickening of membranes in small vessels and capillaries and by accelerated and enhanced atherosclerosis of the larger vessels. These blood-vessel changes are believed to be responsible for the serious complications mentioned above which are a result of neuropathy (nerve disease), nephropathy (kidney abnormality), angiopathy (cardiovascular malfunction), and retinopathy (retinal noninflammatory disorders). The major question still to be answered is whether better blood-glucose control, such as that provided by implanted and programmable insulin pumps, will alleviate the long-term complications of diabetes.

UNM Study of Insulin Control

The external insulin pumps were used by the School of Medicine to establish the characteristics of insulin supply needed to normalize a diabetic patient's blood chemistry. In effect, it was necessary to know the degree of insulin control required for an artificial system to simulate a normal pancreas. Because the biological mechanisms of insulin supply are complex, it was also important to establish the best body site for delivering insulin.

Before these concerns could be addressed, the function of the normal endocrine system had to be understood. In a non-diabetic, the hormone insulin is released into the blood stream from a collection of cells within the pancreas called the islets of Langerhans. Insulin then passes directly into the liver through the blood system. The role of insulin in the metabolism cycle is to stimulate the body's cells to remove sugar from the blood stream and utilize it.

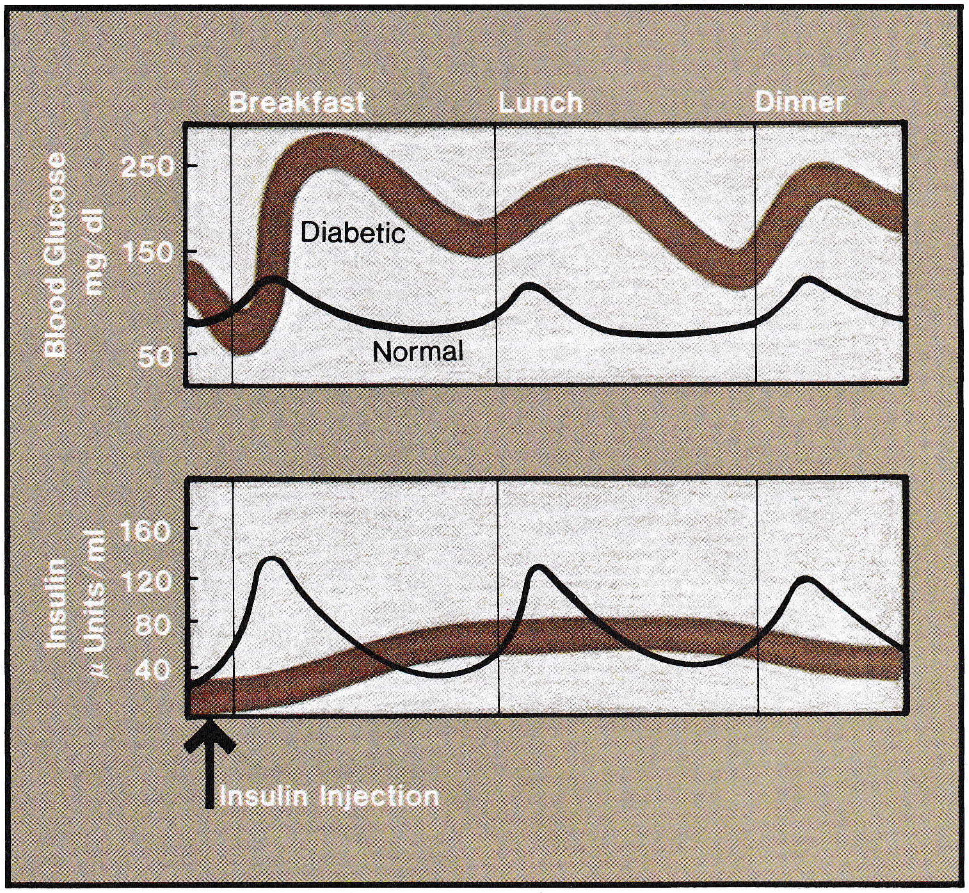
An important consideration is that, in the normal case, insulin is released directly into the blood stream when needed. However, when a diabetic individual injects insulin subcutaneously, i.e., not directly into the blood stream, a considerable length of time passes before the insulin reaches the blood. Thus the net glucose control process is complex, and it is important to determine an infusion site that permits rapid insulin absorption into the blood to more nearly approximate the normal situation. The medical conclusion is that the peritoneal (abdominal) cavity is a preferred location for insulin delivery.

External pumps developed by others infuse insulin steadily through a small needle placed through the skin, and they represent a great improvement over daily insulin injections. However, the implanted pump has a significant advantage: it can provide insulin to a site similar to normal pancreatic delivery. When insulin is delivered into the peritoneal cavity, it enters the portal vein through capillaries and flows to the liver to aid the body in regulating glucose.

Shown below are blood glucose and insulin levels for normal and insulin-dependent diabetic individuals during a typical three-meal day. In a normal individual, blood-insulin levels increase sharply after a meal because of pancreatic stimulation. Depending on the type of food consumed, body weight, activity level, and several other factors, this increased insulin flow is typically about a factor of ten over the normal rate.

For a diabetic, this insulin supply must be supplied artificially. A single morning injection of insulin is common, but diabetics may use multiple injections throughout the day to improve their blood-glucose control. Unfortunately, the long diffusion times involved in subcutaneous delivery do not permit accurate simulation of normal blood-insulin levels. However, as

Blood-glucose and insulin levels for a 24-hour period for a normal individual (black curves) and for a diabetic (colored curves). For a non-diabetic, glucose levels normally run about 100 mg/dl (milligrams of glucose per deciliter of whole blood) and, importantly, they do not vary significantly over a 24-hour period. It is assumed that the diabetic took the usual subcutaneous injection of combined long-lasting and regular insulin prior to breakfast. Note that after a meal, the glucose level rises much higher in the diabetic case. The amount of this rise varies considerably but may be as much as 300 to 400 mg/dl. In contrast to the normal curve, which increases markedly at mealtime, the diabetic's insulin history shows a flat distribution throughout the day as a result of the morning injection.



studies have shown, peritoneal-cavity insulin delivery can provide excellent agreement with normal blood-glucose and blood-insulin levels.

In addition to abnormal insulin and glucose levels encountered in a diabetic individual, imbalances are often present in other important hormones. Some evidence suggests that these imbalances are related: that better control of insulin and glucose will readjust the other blood chemicals to normal values. Research in this area is continuing with the aid of the implanted insulin pump.

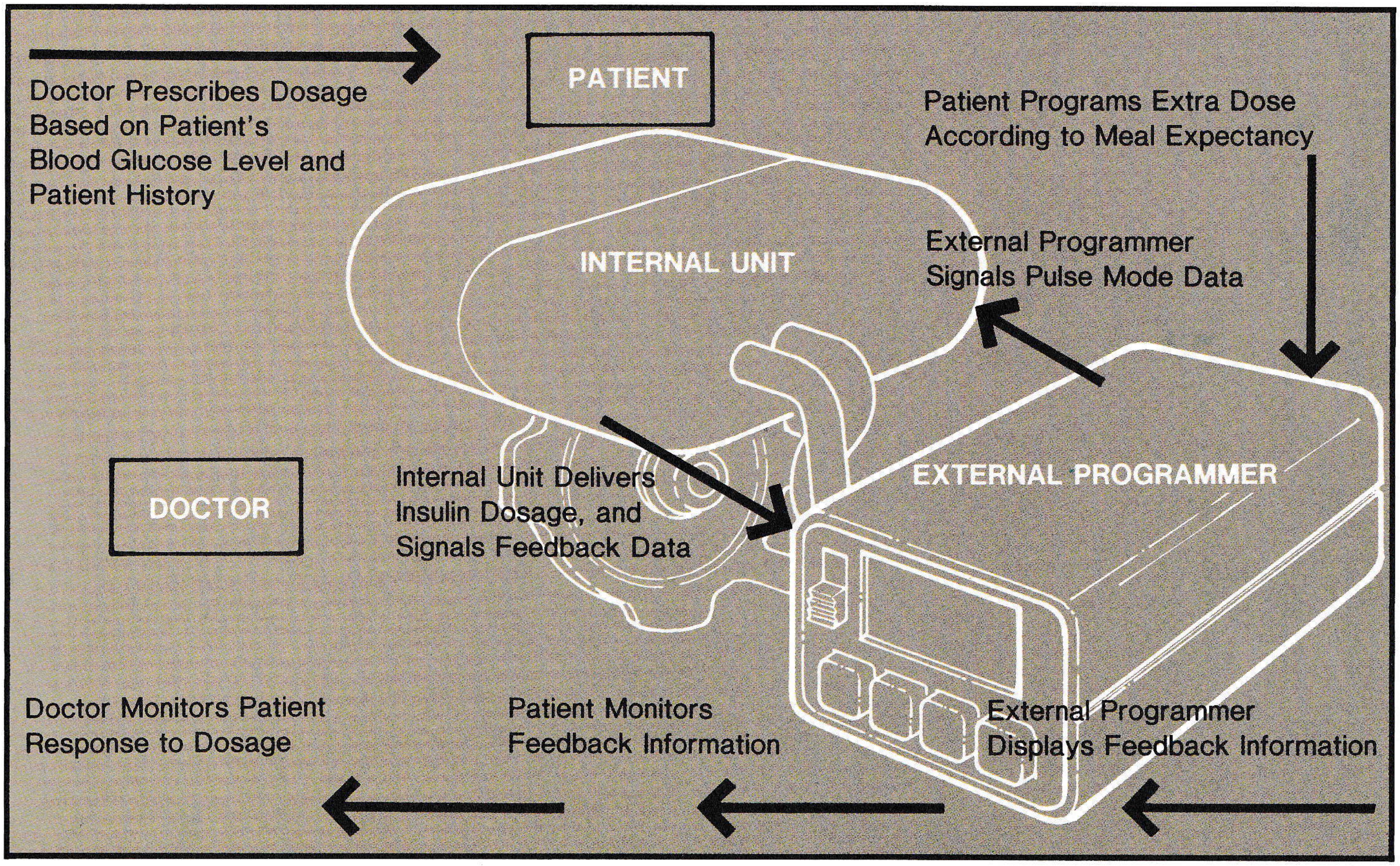
With the new system, the physician can specify the necessary control by prescribing insulin needs to the patient. The patient and the physician, using separate programs, transmit this information to the implanted pump via a two-way communication link using the external programmer.

The block diagram below shows the components of the system and illustrates the control concept. This open-loop approach requires periodic testing of blood-glucose levels to ensure accurate insulin-need calculations.

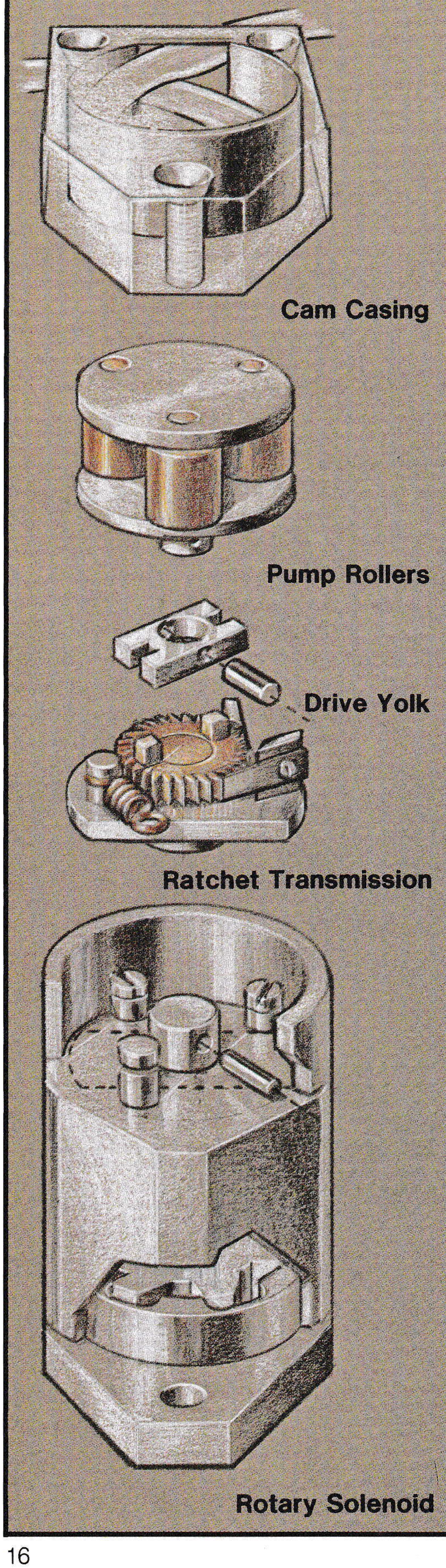
When patients have been on peritoneal delivery for only a few days, their blood glucose and insulin levels become nearly normal. This level of control is not possible with the usual external injections. Because the peritoneal cavity is susceptible to infection, an external pump with a supply catheter into that region is not feasible.

Besides providing medical advantages, an internal pump — as compared to a belt-mounted external unit — enables the user to lead a more normal life. Worry about protecting the external unit, plus other human factors such as appearance, make the internal device desirable. Children, especially, would benefit from an implanted insulin delivery system because it is not noticeable and does not restrict their activities.

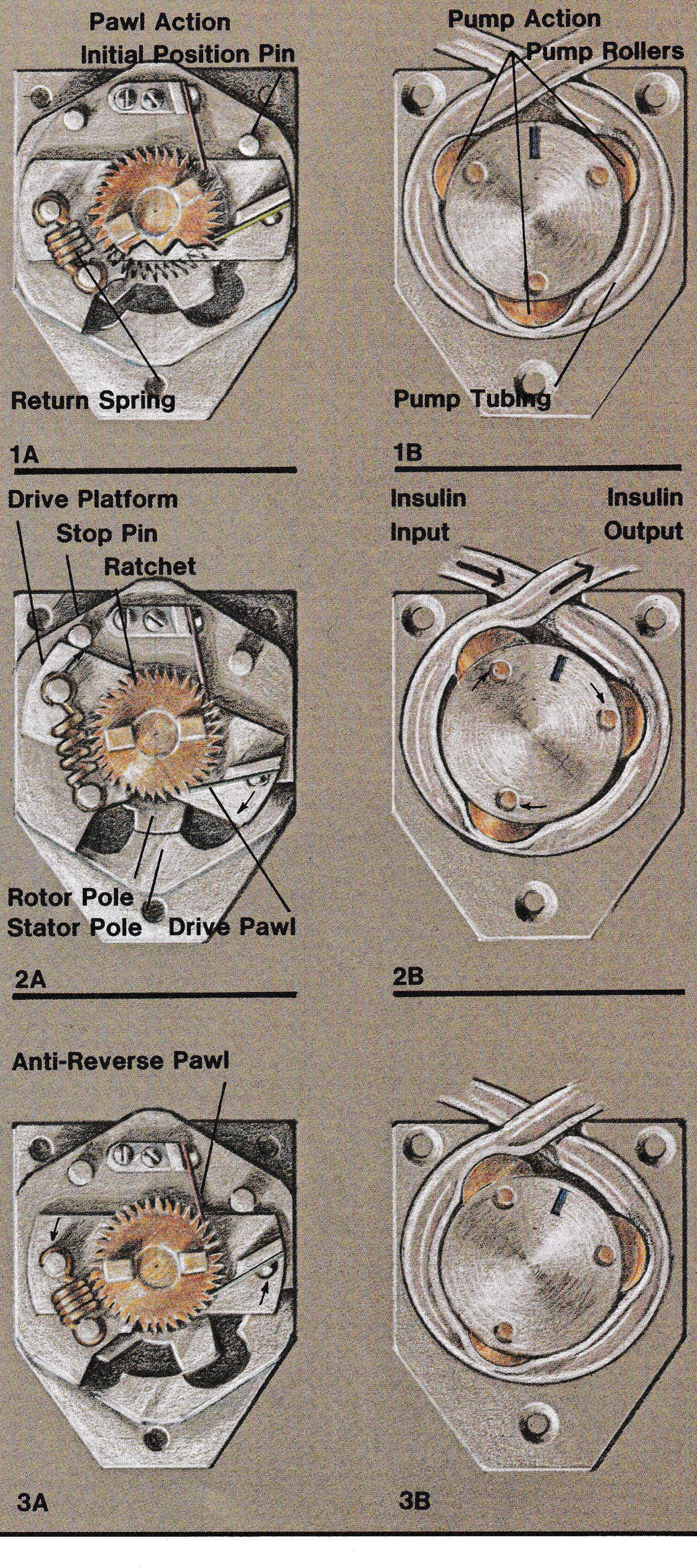
Functional diagram of the remotely programmable insulin delivery system. Programming is accomplished by inductively sending and receiving messages between the external programmer and the implant. Program instructions are determined by the patient and physician based on meal characteristics, blood-glucose levels, and experience.


Doctor Prescribes Dosage Based on Patient's Blood Glucose Level and Patient History
PATIENT
Patient Programs Extra Dose According to Meal Expectancy
INTERNAL UNIT
External Programmer Signals Pulse Mode Data
DOCTOR
Internal Unit Delivers Insulin Dosage, and Signals Feedback Data
EXTERNAL PROGRAMMER
Doctor Monitors Patient Response to Dosage
Patient Monitors Feedback Information
External Programmer Displays Feedback Information

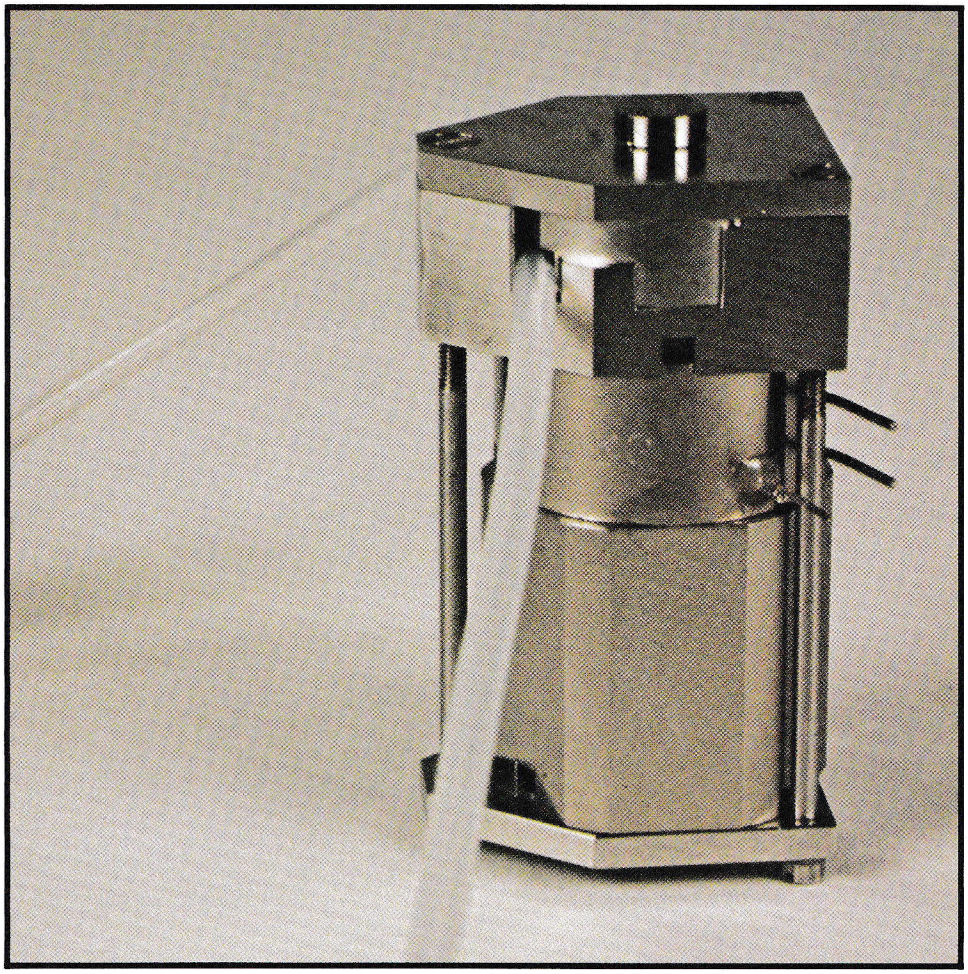
EXPLODED VIEW OF PUMP ASSEMBLY


Cam Casing
Pump Rollers
Drive Yolk
Ratchet Transmission
Rotary Solenoid

DRIVE AND PUMP OPERATION SEQUENCE


Pawl Action
Initial Position Pin
Return Spring
1A
Pump Action
Pump Rollers
Pump Tubing
1B
Drive Platform
Stop Pin
Ratchet
Rotor Pole
Stator Pole
Drive Pawl
2A
Insulin Input
Insulin Output
2B
Anti-Reverse Pawl
3A
3B

Latest model of the peristaltic insulin pump. When the three-roller pump is incremented by one stepping pulse, a 1-microliter droplet of insulin is forced through a small (1.5-mm inside diameter) silicone rubber tube leading to the delivery catheter. Pulse rate is variable from 4 droplets per hour in the background mode to 1 droplet every 8 seconds for variable durations in the pulse mode.

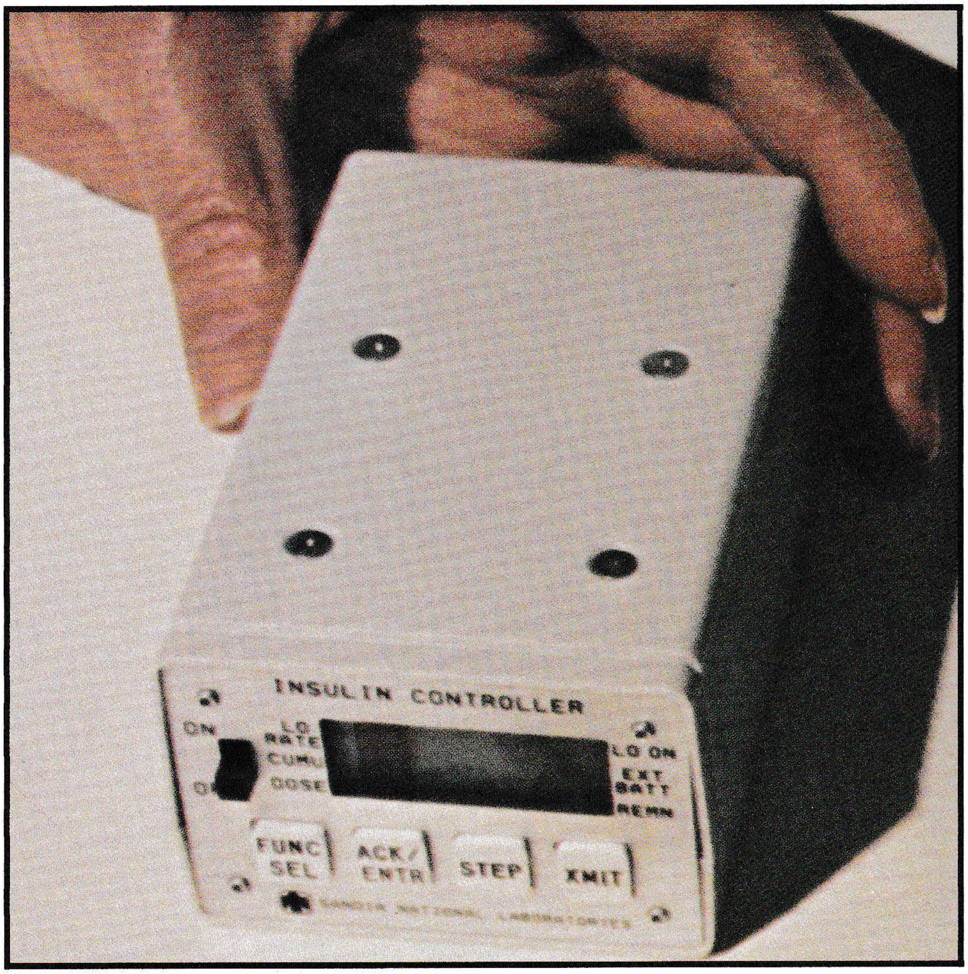


The exploded drawing shows the major components of the pump assembly. The cam casing provides the eccentric surface to enable the pump rollers to alternately constrict and release the flexible tubing. Precision control of the insulin dose occurs when the rollers step forward 5 degrees from the initial position (1A,B), thereby forcing along an insulin droplet. During this pump stroke (2A,B), the drive platform ratchets forward as a result of the solenoid operation, and the pump rollers are moved ahead. During the return stroke (3A,B) the drive platform is moved back to the initial position by spring action, but the rollers, now incremented, are stationary. Thus the rollers only move in one direction and, as a result, impart a positive step motion to the insulin within the tubing.

Insulin Pump

A number of pump types have been developed for drug infusion studies. For insulin delivery, Sandia initially considered bellows, piezoelectric, and peristaltic pumps operated by a dc motor. We chose a system that uses a peristaltic pump head coupled to a rotary solenoid motor that was developed for weapon applications. Our peristaltic pump consists of successive rollers passing over the walls of a flexible rubber tubing, thereby forcing along the insulin within.

This pump is valveless, self-priming, and has a delivery rate independent of pressure on both the inlet and outlet. The controls are designed to stop the insulin flow in case of various system failures using techniques adapted from nuclear safety technology. The variable delivery rate is controlled by the electronic circuitry. During reliability testing, the pump and silicone rubber tubing were cycled over two million times — the equivalent of 10 years of normal operation — without significant wear. The power supply is energized by two AA-size lithium-thionyl-chloride cells, which will operate the system for two to three years.



The hand-held external programmer uses an RCA 1802D microprocessor system which interfaces with the low-power integrated circuitry and the analog and bipolar devices used to provide two-way communication with the implanted system. The microprocessor has 1024 eight-bit words (bytes) of read-only memory and 128 bytes of volatile memory. The human input to the programmer is through a keyboard, and the output is read from a liquid-crystal display.

Electronics

The implanted electronics package uses low-power-consumption integrated circuits, a signal receiver and transmitter, and analog devices, all mounted on a ceramic thick-film circuit. The housing is made of titanium because of its biocompatibility. In addition, titanium provides high strength, minimum weight, and allows for signal transmission. Various weapon programs provided the technologies for the adhesives, the laser-welded hermetic seal on the enclosure, and the communication link.

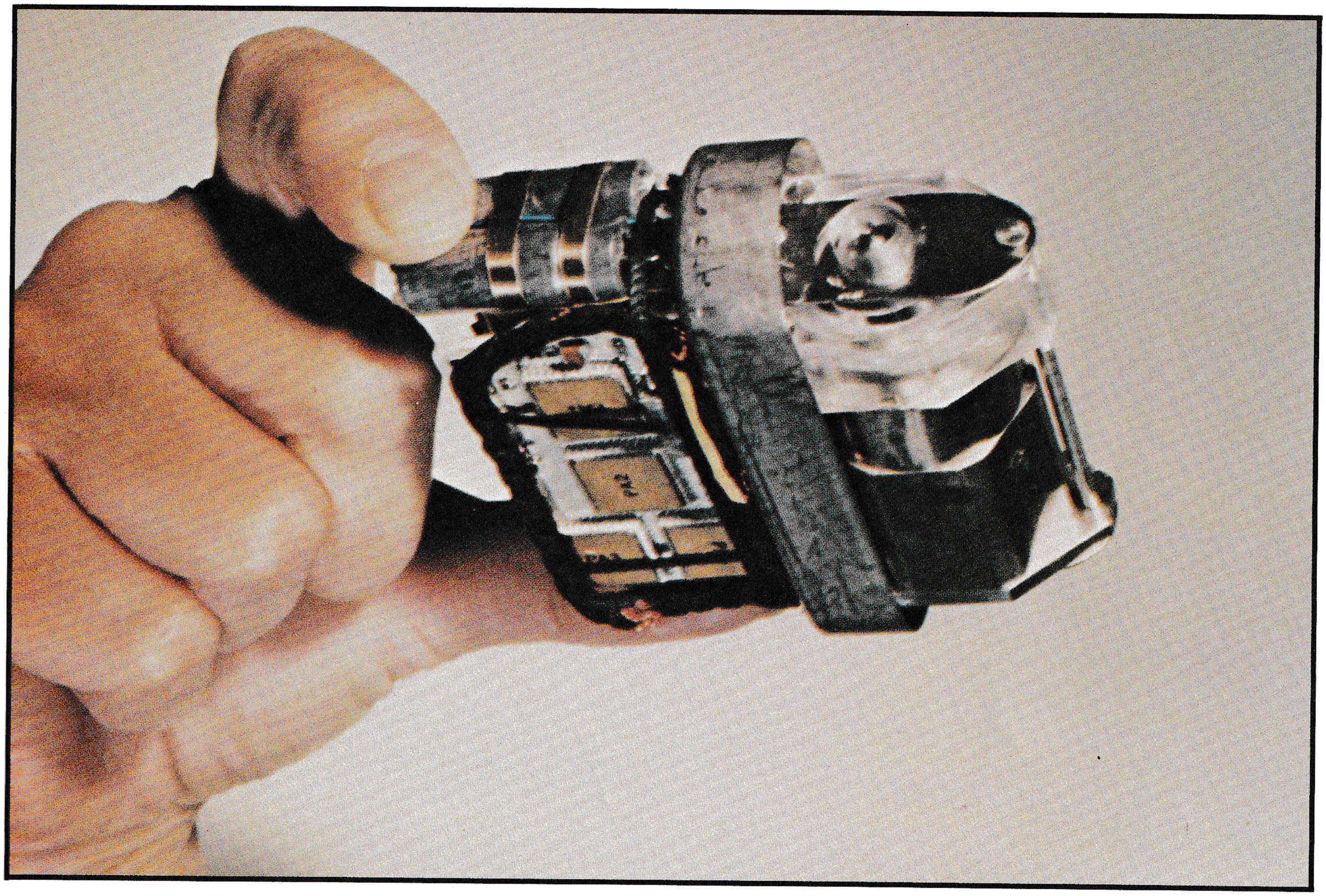
Command and program information for the basal and pulse rates are entered into the microprocessor in the external programming module by a four-button keyboard. A unique identification code limits access to the implanted controller, thus ensuring that electromagnetic fields generated by appliances and communication transmitters will not alter the insulin delivery program. Two-way communication is used to verify the stored program in the implant module, providing further assurance that the instructions to the internal program have been received correctly. Finally, there is a system monitor that receives and interprets diagnostic information from the implanted system.

System Use

When the patient is not eating, the need for insulin is low, and the pump is programmed to deliver a low (basal) or maintenance rate similar to that released normally by the pancreas. The implanted system can be programmed for 15 basal rates, permitting control of the basal insulin dose from a single 1-microliter droplet every minute to one every 16 minutes.

Before the patient eats, he calculates his increased insulin need based on the expected meal characteristics and his existing blood-glucose level. Using the hand-held programmer to transmit his instructions inductively through the abdominal wall to the implant, the patient orders one of 15 mealtime doses. These doses are delivered at a higher rate for a duration of one to 16 minutes. At the end of the mealtime delivery, the programmer automatically returns the pump to the lower basal rate of insulin supply.

In addition to the control function, the programming module also receives data transmitted from the implant concerning the amount of insulin delivered, the amount remaining to be delivered for an ongoing mealtime dose, and



The implanted electronic control unit stores the delivery data, controls the pump operation, communicates with the external programmer, and provides a status report on the battery and pump. Twenty-six low-power integrated circuits are enclosed in eight hermetic packages mounted on both sides of an aluminum-oxide substrate. The implant module uses two sealed 3.66-volt batteries and a capacitor-discharge unit to power the pump and electronics.

information about battery strength and other system diagnostics.

For the Future

In our joint program with the UNM School of Medicine, we have now shown the feasibility and effectiveness of the implanted insulin delivery system for controlling a diabetic's blood glucose. The next step is to expand the program to include a larger number of implanted patients. In addition, we are continuing to refine and improve the insulin delivery system. Because of improvements in the pump and motor, the next version of the implant system is expected to be about half the present size, with battery life doubled to approximately five years. The National Institutes of Health, who have supported the UNM-Sandia program since the beginning, have recently provided a grant for our participation in a three-year study to continue this research. Further, several US health-care companies are interested in using this technology to manufacture the insulin delivery system and provide it for clinical trial to medical research teams throughout the country.

The concept of variable delivery of drugs from an implanted system has potential medical implications beyond insulin delivery. For example, this technique is now under evaluation for chemotherapy use in cancer treatment, as well as for the delivery of other life-sustaining drugs.

Implant

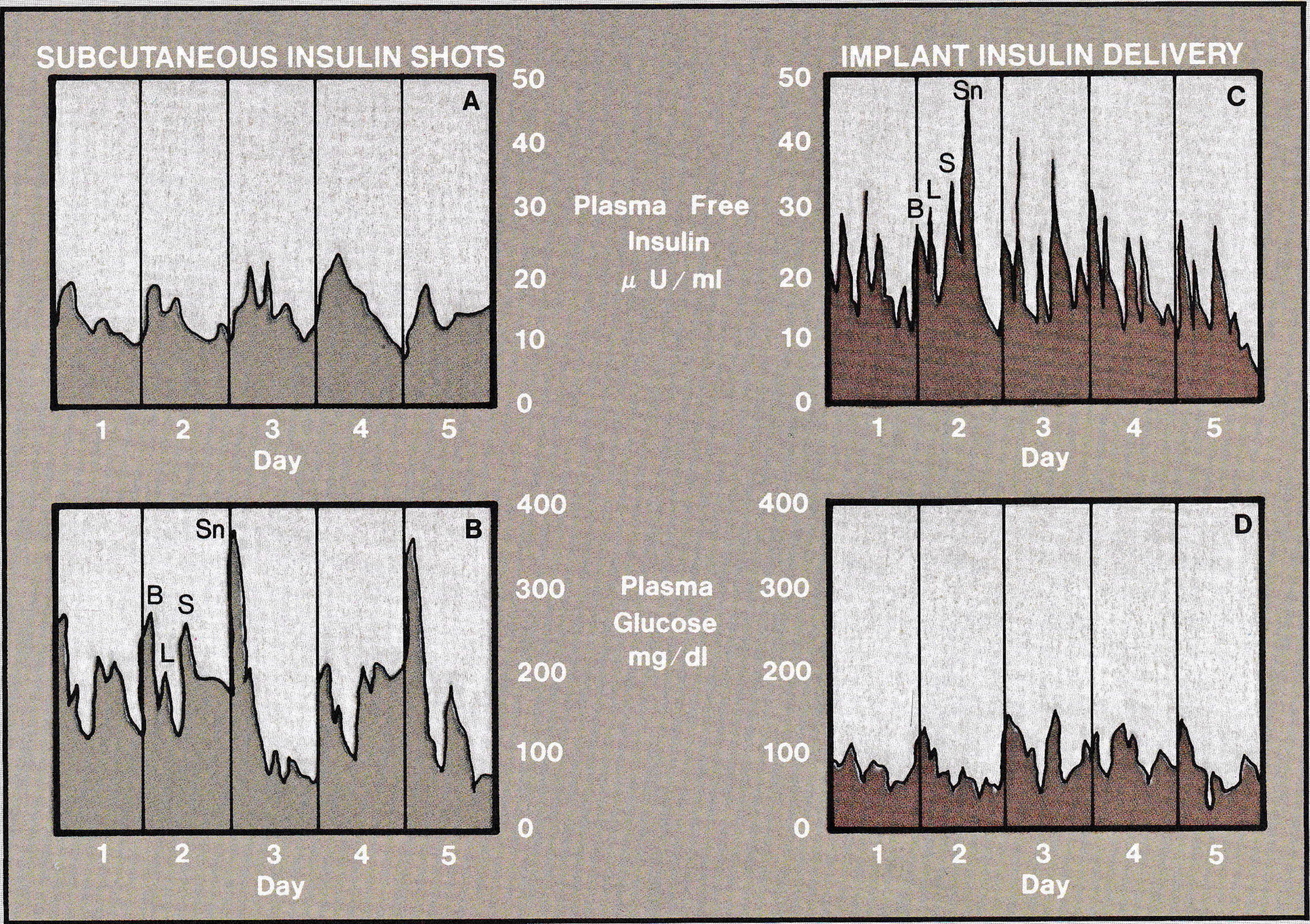
Monte Patterson, 41, of Albuquerque, is the world's first recipient of an implanted, electronically controlled, and programmable insulin pump. The system was implanted at the University of New Mexico Medical Center. Within a matter of days from insulin turn-on, Patterson, who has been a diabetic since age 5, exhibited normal blood-glucose levels.

The figure at right shows the location of the implant within Patterson's body. Insulin is delivered by the implanted pump to the abdominal cavity where it is absorbed into the blood system leading to the portal vein. From there it is transported by natural blood flow to the liver in a manner similar to the normal case.

For the first time since childhood, Patterson is able to eat normally. More importantly, he believes that his overall health has improved, and he now (after several years of incapacitation) feels capable of returning to work.

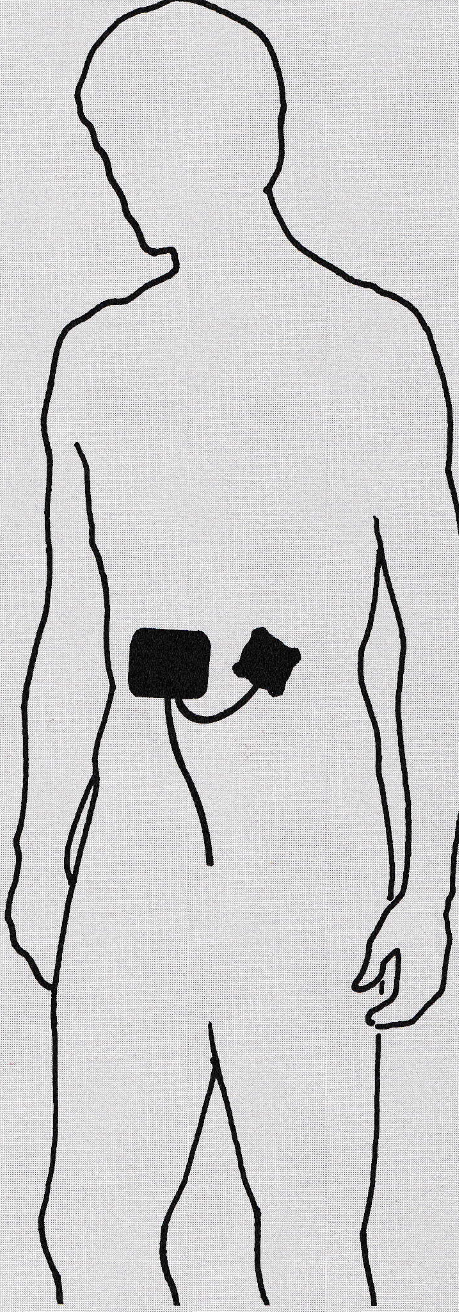
The chart below shows the substantial improvements in Patterson's blood-glucose and blood-insulin levels that occurred after the implant. Values were measured hourly over a five-day period prior to implantation when insulin was supplied by subcutaneous injection. A corresponding series of measurements was made during the third month after implantation. Blood-glucose levels typically near 100 mg/dl are considered normal. These measurements were provided by Drs. R. P. Eaton and D. S. Schade of the UNM School of Medicine. Mr. Patterson has approved the release of this information.

Insulin and blood-glucose measurements for Monte Patterson showing the difference between insulin delivery by shots (A,B) and by the implanted insulin pump during the third month of operation (C,D).

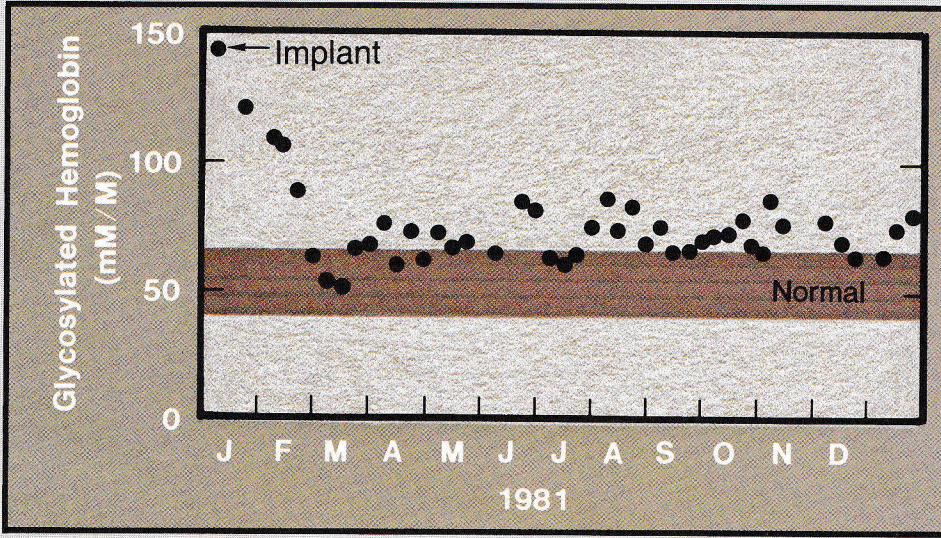


With sustained elevated glucose levels, the overall blood chemistry becomes altered. In particular, hexose, a sugar molecule, attaches itself to a red-blood cell. The result is called glycosylated hemoglobin, or GlyHgb. This process is irreversible, and can be corrected only as new red blood corpuscles replace the GlyHgb within the typical three-month lifetime of these blood cells. Because of this feature, GlyHgb is an important measure of the accumulated blood-glucose effects on the patient. Patterson's history of GlyHgb illustrates the improvement in blood chemistry provided by the implanted pump. Note that his GlyHgb was substantially improved well within three months after the beginning of programmed delivery. It is hoped that this degree of control will reduce or eliminate the long-term complications of diabetes.

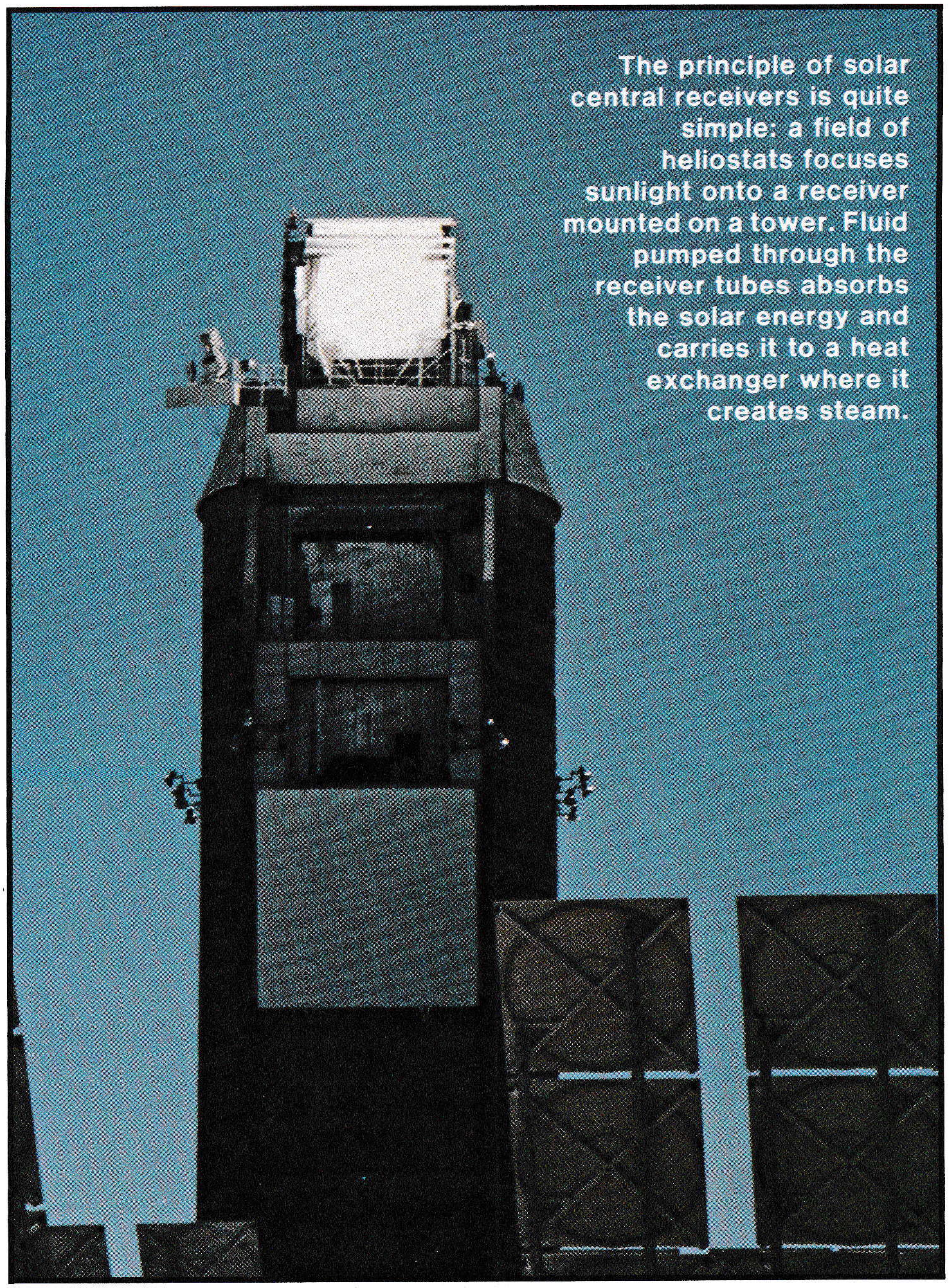
For further information, call Gary Carlson, (505)844-5581.



The titanium enclosure containing the batteries, motor, pump, and electronic controls is located on the right side of the body just below the rib cage and between two layers of muscle. The 4-cc-capacity silicone-rubber insulin reservoir is implanted under the skin to allow periodic refilling by syringe. A 15-cm long silicone-rubber catheter transmits insulin to the peritoneal cavity, where it enters the portal vein and travels to the liver. The system is coated with medical-grade silicone rubber to prevent biological rejection.



Red blood-cell glycosylated hemoglobin (GlyHgb) levels for Monte Patterson, showing improved diabetic control as a result of the implanted insulin delivery system. This improved control, as diagnosed by the GlyHgb levels, is believed to be an important factor in eliminating the long-term complications of diabetes.



The principle of solar central receivers is quite simple: a field of heliostats focuses sunlight onto a receiver mounted on a tower. Fluid pumped through the receiver tubes absorbs the solar energy and carries it to a heat exchanger where it creates steam.

Experiments and prototype testing point to molten nitrate salts as an effective and economical fluid for both heat transfer and heat storage in solar central receivers.

Molten Salts: Dual Use In Solar Central Receivers

Solar central receivers are one of many alternative commercial energy sources under study for the Department of Energy. In first-generation receivers like the one at Barstow, California, solar energy converts water pumped through receiver tubes to steam. The steam either drives a turbine to generate electricity or provides process heat. If the heat in the steam is to be stored for later use, the steam is piped to an exchanger where its heat is transferred to an organic fluid stored in a thermal storage tank. When needed, this heat is retrieved through a second exchanger and used to create steam.

In an attempt to reduce cost and increase efficiency, a new concept — circulating the same fluid through both the receiver tubes and the storage tank — is being tested for use in second-generation receivers. The concept has been under consideration since early in the solar central receiver program; the question, however, has been what liquid to use. Several were proposed: molten sodium (technology based in the nuclear industry); air and helium (for high-temperature applications); oil (for low-temperature applications), and molten salts.

Because of their widespread use in industry, there was considerable interest in molten salts as an alternate fluid in solar central receivers. This article describes our investigation of this possibility.

After eliminating salts that were corrosive, expensive, or toxic, we selected a commercially available nitrate salt mixture (60% $NaNO_3$ and 40% KNO_3) as the most likely candidate for central receiver application. This product is used in industry as a heat-transfer fluid and as a heat-treatment bath. These are both isothermal operations with a top operating temperature of about 450°C. Even though molten salts are widely used, there was little documentation of their physical properties, corrosive behavior, or environmental effects either in nonisothermal operations or at the temperature range of interest for solar central receivers (290-565°C). A number of experimental programs were begun to address these uncertainties.

Specific molten nitrate salt research projects undertaken at our Livermore facility included:

- Immersion tests of a variety of metal alloys at various temperatures.
- Corrosion studies of 304 and 316 stainless steel and Incoloy 800 using thermal convection loops.
- Studies of creep and the effects of deformation on the corrosion characteristics of Incoloy 800.
- Evaluation of the stress corrosion cracking susceptibility of Incoloy 800.
- Construction and testing of a solid electrolyte oxide ion probe to study possible corrosion problems in molten nitrates.
- An investigation of the thermal stability of nitrates at high temperatures.
- Determination of the relationships between pressure, temperature, and salt composition under conditions of fixed volume and pressure.
- Design and use of an apparatus to measure the viscosity, surface tension, and density of (Na, K)NO_3 from 300 to 600°C.
- Measurement of the heat capacities of $NaNO_3$, KNO_3, and (Na, K)NO_3 between 100 and 600°C.
- Determination of the phase diagrams of $NaNO_3$-KNO_3.

Oak Ridge National Laboratory studied corrosion behavior of 304 and 316 stainless steel and Incoloy 800 in molten nitrate salt. The University of the State of New York at Buffalo studied a phenomenon observed in Incoloy 800 — the formation of thin passivating oxide layers that inhibit corrosion in molten salts. To determine whether an open, closed, or breathing system was needed for salt storage, EIC Corporation, Inc., studied the interactions of molten (Na, K)NO_3 with water and carbon dioxide in air. The Norwegian Institute of Technology measured the thermal conductivity of molten (Na, K)NO_3 mixtures and determined the effect of impurities on their thermal conductivity.

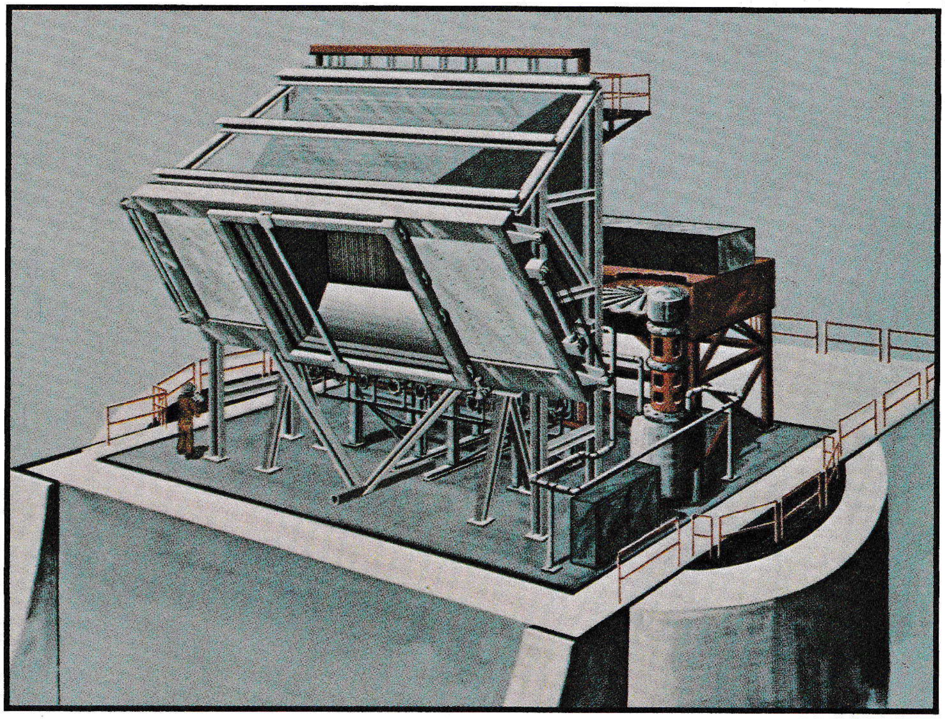
A prototype molten salt receiver was built by Martin Marietta and tested at Sandia's Central Receiver Test Facility in Albuquerque. Between August 1980 and March 1981, the receiver was run for about 500 hours, half at full power (all heliostats on), which produced about 5 megawatts thermal. After more than 250 thermal cycles, researchers reported "no major hardware problems, no safety issues, and no major incompatibilities. The calculated receiver efficiency was 85 ± 5%."

Martin Marietta is now fabricating a subscale molten salt storage subsystem that can be scaled up to a full-size system. This component and a salt/steam heat exchanger will both be tested at the Central Receiver Test Facility when they are available.

The research required for this program has added to the fundamental knowledge of molten salt chemistry, and to our understanding of material compatibility. Based on what we have learned, we feel confident that the molten nitrate salt technology developed at Sandia for central receivers will also find broad application in other fields — notably high-temperature gas-cooled reactors and different types of turbines.

For additional information, call Bob Carling (415) 422-2206

The Martin Marietta receiver was tested at the Central Receiver Test Facility. Molten salt was heated by pumping it back and forth through headers and Incoloy 800 tubes. The molten salt was then run through an air cooler (to simulate the loss of heat that would occur in a heat exchanger used to generate steam), then into a sump and back up to the first header. Calculated receiver efficiency was 85 ± 5%.



Another Weapon Technology Spinoff:

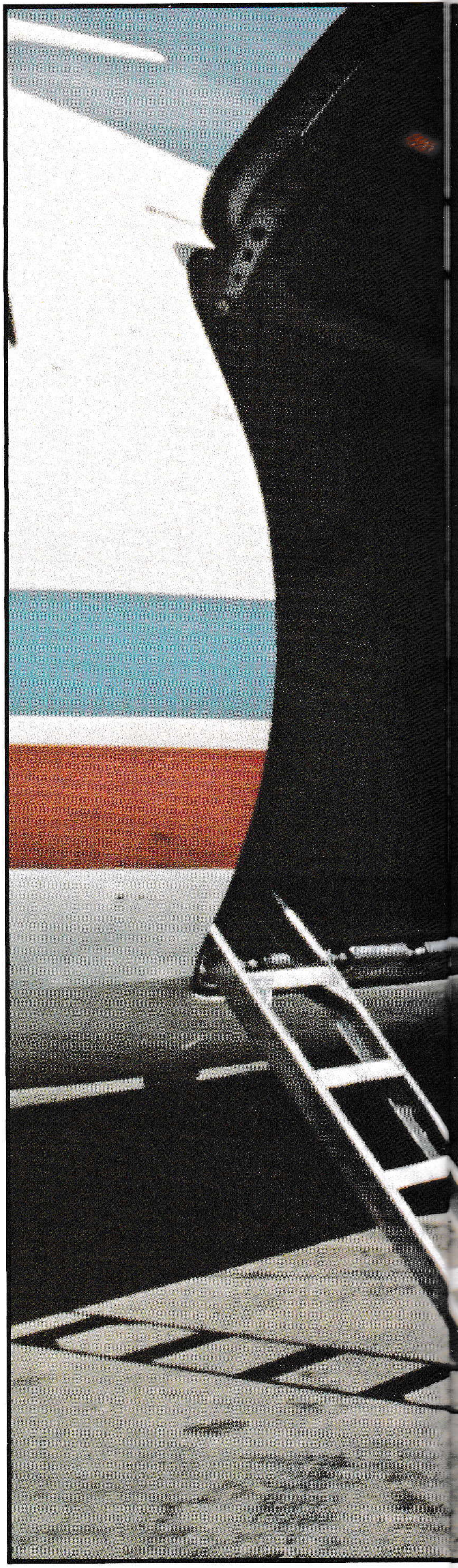
Packaging of Radioactive Reactor Samples for Safe Air Transport

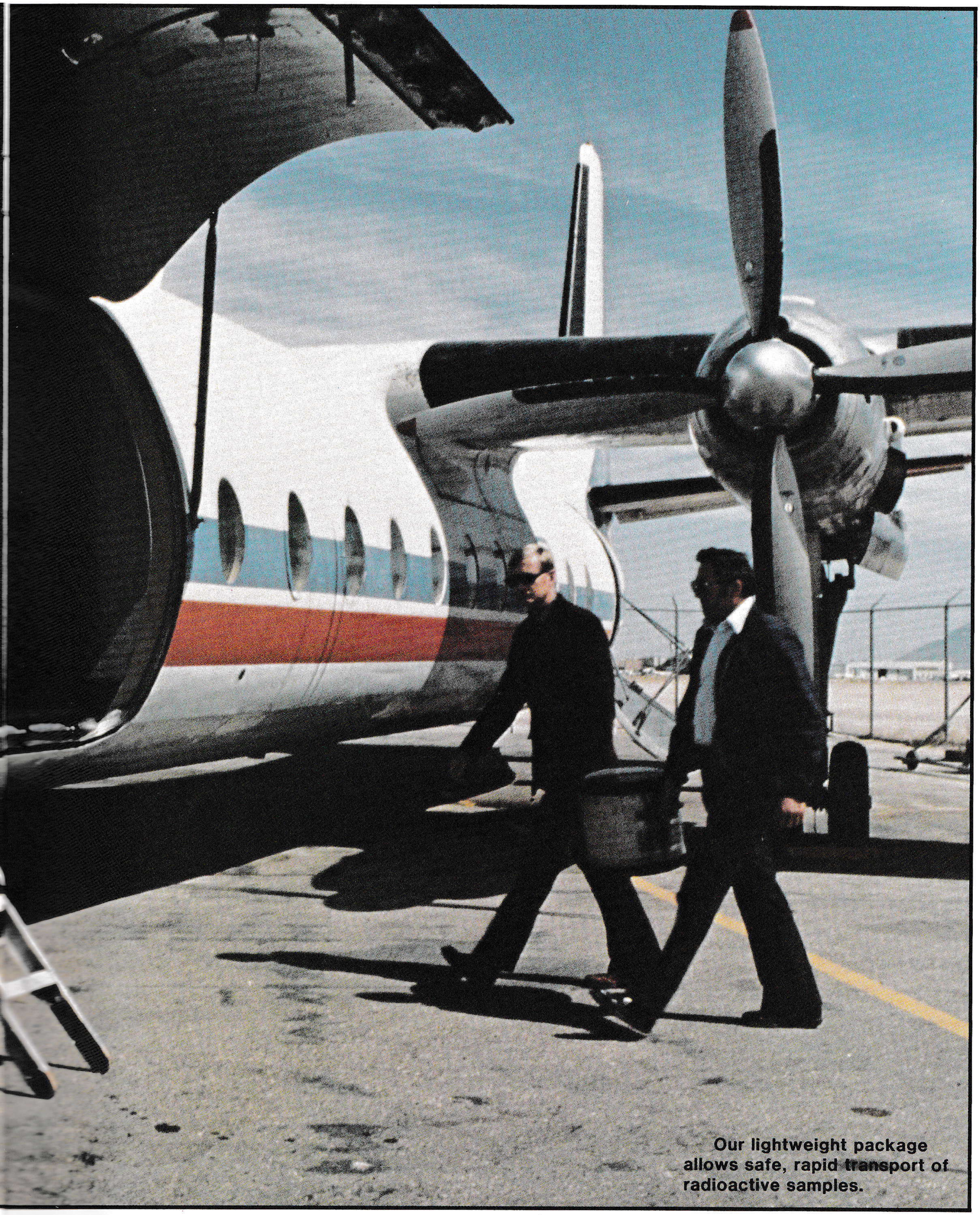
Shipping radioactive reactor samples internationally requires an air-transportable package with very special qualifications. We designed one that meets or exceeds all US and international safety requirements. It has been licensed by the Nuclear Regulatory Commission.

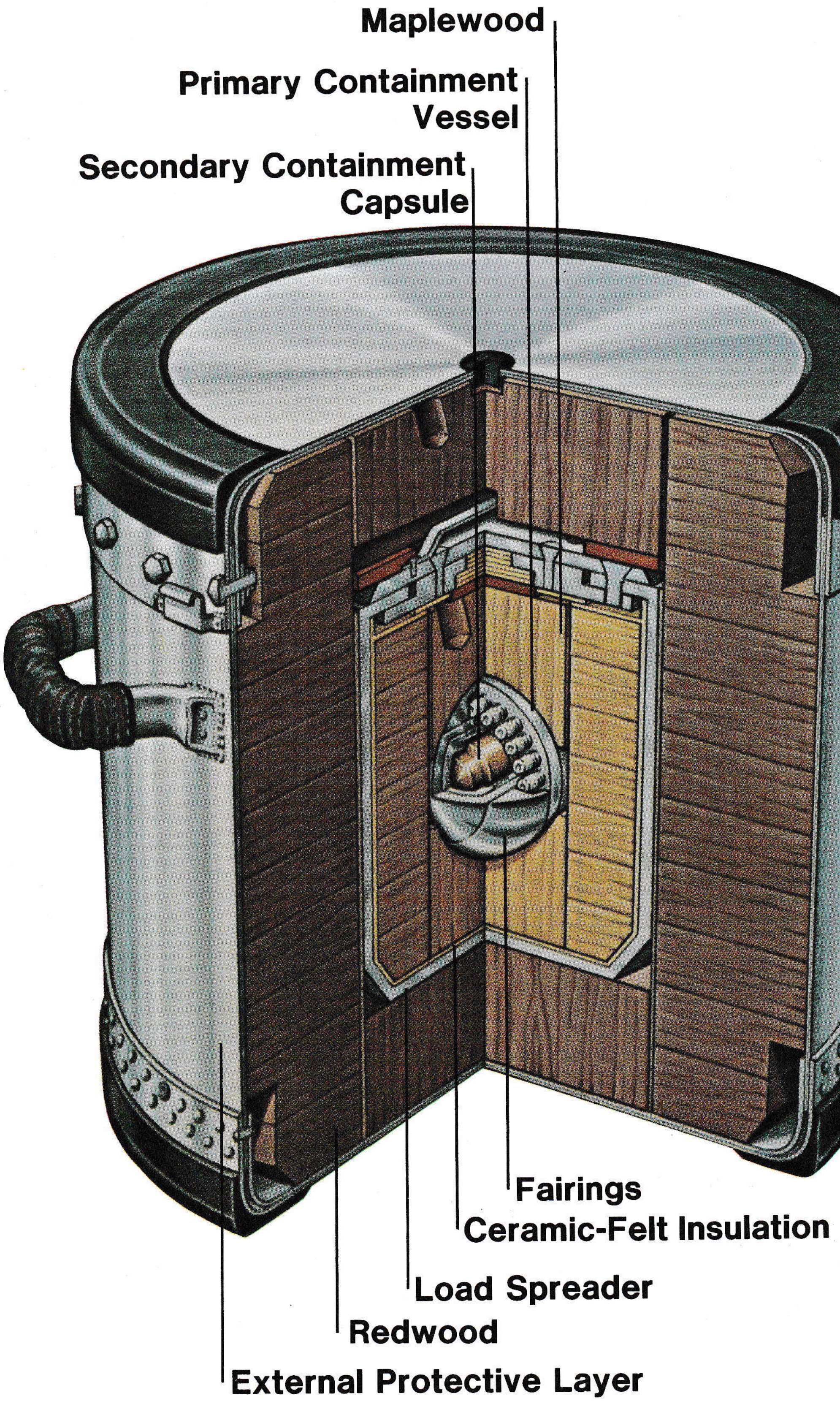
An effective international safeguards program demands quick handling and processing of radioactive reactor product samples so that misuse of reactor fuel (to produce weapon-grade uranium or plutonium) can be promptly detected. The samples can come from countries all over the world and must be transported rapidly. Air transport is the obvious answer, but aircraft accidents can be more severe than surface transport accidents.

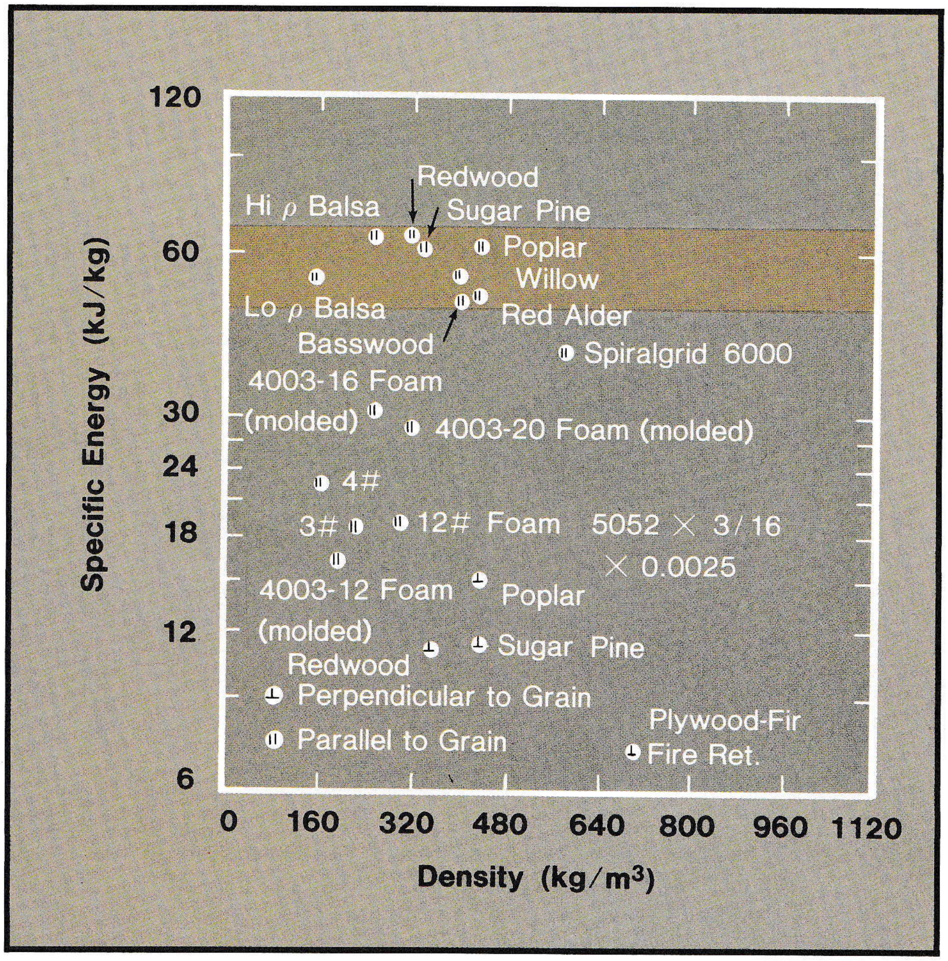
Concerned for public safety, national and international legislative and regulatory groups wanted a safe, compact, lightweight, accident-resistant, air-transportable package in which to ship small samples of plutonium, uranium, and fission products. The International Support Branch of the Department of Energy's Office of Safeguards and Security asked Sandia to develop such a package.

Our design challenge was to provide a virtually unassailable sealed pressure vessel that met all specifications for plutonium containment, shielding, and criticality — a container that would meet all environmental criteria for normal use and could survive severe accidents as well. Survival criteria ranged from normal environments such as heat and cold, pressure and vibration, to accident environments such as impact, crushing, puncture, slashing, fuel fire, and water immersion. Additionally, the container had to provide adequate payload space, yet be small and simple to use.




Our lightweight package allows safe, rapid transport of radioactive samples.


Maplewood
Primary Containment Vessel
Secondary Containment Capsule
Fairings
Ceramic-Felt Insulation
Load Spreader
Redwood
External Protective Layer



Specific energy absorption capabilities for several materials are shown perpendicular and parallel to the grain of the material.

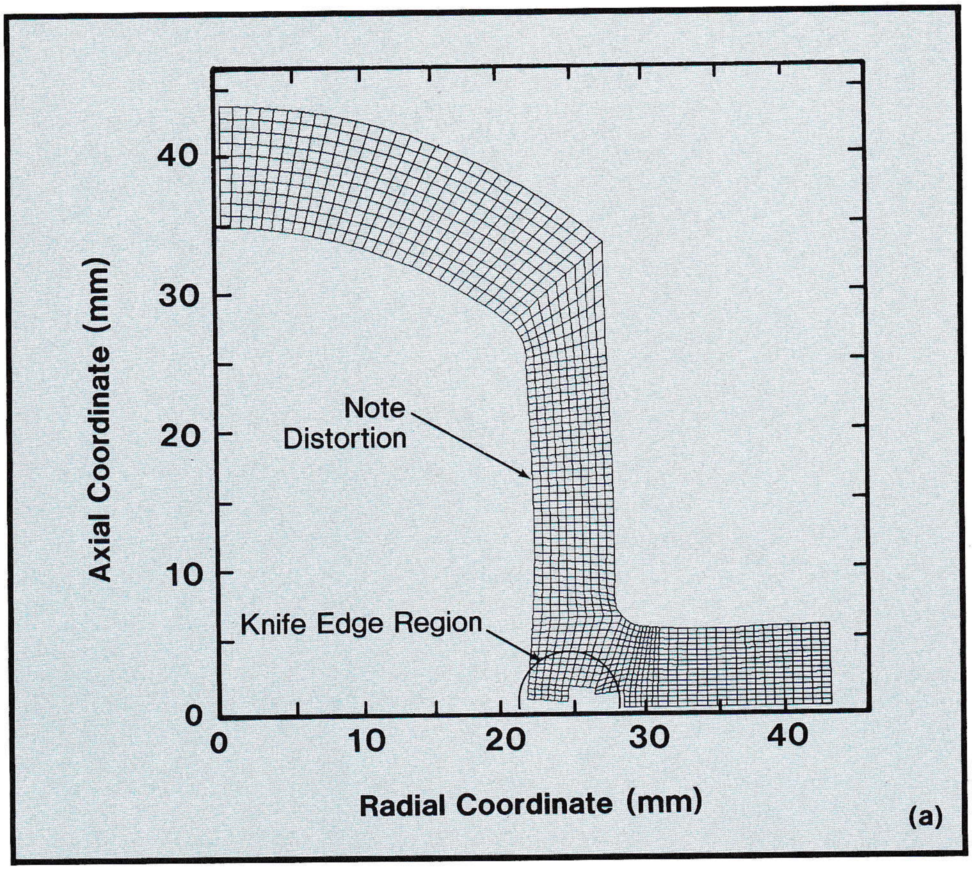
The Package

A large part of the design and analysis for a small, transportable container was based on our experience in crash protection of nuclear weapons, and on research and development work in support of an earlier program in which we developed a large crash-resistant transport package.

Our basic design approach to both packages was the same — to protect the primary and secondary containment vessels against normal and accident environments with a cocoon of metal, wood, and thermal insulators. The primary containment vessel protects and isolates the secondary capsule that holds the radioactive material. Double containment is required for sources greater than 20 curies.

Samples (plutonium, uranium, and certain isotopes) are sealed in a secondary containment capsule made of Nitronic 60, a very tough austenitic alloy treated with nitrogen that has inherent lubricity while retaining the usual properties of stainless steel. The primary containment vessel is made from A-286 iron-base superalloy (high toughness) and is assembled with 20 bolts of the same alloy. A seal is formed by knife-edge sealing beads located in each hemisphere, which cut into a preformed copper gasket when the unit is bolted shut. An integral shear shoulder is included in the joint so the bolts are loaded in tension only. Fairings fit over the vessel, covering the bolts and giving the vessel a spherical shape. These fairings serve to distribute loads resulting from accident environments. A layer of maple wood, selected because of its high ultimate crush strength, surrounds the containment vessel. A load spreader made of titanium with a ceramic-felt backface insulation surrounds the maple. This interstitial load spreader distributes any inertial deceleration loads on the primary containment vessel resulting from package impact. It also limits penetration of objects that could slash or puncture the vessel or the surrounding maple structure.

Redwood was selected for the outer protective layer because of its high specific energy absorption and its good char performance — a capability to maintain a definite structure after heating, which is essential for fire protection. A double-walled drum of 304 stainless steel provides the external protective layer and the final package configuration. This tough and ductile overcladding also retains the redwood within the confines of the package when large deformations are caused by high-speed collision with an unyielding target.



Deformed displacement field, at 100X magnification, for a primary containment vessel subjected to 22.6-MPa internal pressure at 582°C

Structural Design, Analysis, and Testing

The containment vessel was designed to provide extreme strength in severe combined environments such as high temperature and pressure. A structural model of the vessel was developed and calculations were made of the internal and external pressures the vessel would sustain during both normal and accident environments. The material properties used in the vessel model varied with the temperature at which the specific load was applied. For instance, the maximum credible pressure the vessel would undergo in an accident (with radioisotopic contents of 3 g plutonium sulfate tetrahydrate powder*) resulted in an internal pressure of 22.6 MPa (3,280 psi) at a temperature of 582°C (1,080°F). This is a bounding temperature for the vessel when it is in place within the package, and is based on the package exterior test temperature of 1010°C.

Stress/displacement field analyses were made using a mesh generator and a finite-element computer program. The problem was modeled as axisymmetric to reduce the calculations to two dimensions rather than three. Determination of the stress field is important because failure, either through brittle fracture or excessive plastic yielding and resultant ductile fracture, must be avoided. Displacements were also determined, since any significant relative displacement of the steel knife-edge and the copper seal at the joint of the primary vessel could result in leakage.

Subjecting the structural model to the worst-case internal pressure of 22.6 MPa resulted in bulging of the vessel and an axial displacement of the knife-edge region. Deformation of the side wall is shown in (a) with the displacement magnified 100 times. The actual deformation field is shown in (b) overlaid by the initial configuration at 21°C. An expanded view of the knife-edge region (c) shows motion of the tip of the seal. The displacement is caused both by applied internal pressure and thermal expansion of the vessel as it is heated to the maximum temperature of 582°C. But even under this displacement, the copper seal material undergoes elastic recovery as the knife-edge begins to move off the seal, thereby reducing the displacement. The model indicated no opening at the outside edge of the seal closest to the bolts. We ran other cases with this computer model, including external pressure application, and plotted isostress contours to aid in our analysis.

We calculated the stress that would result from the external pressure test requirement of 8 hours of immersion at a hydrostatic pressure of 4.1 MPa. This stress level was much lower than we felt the package could handle. To determine the external pressure the vessel could withstand, we

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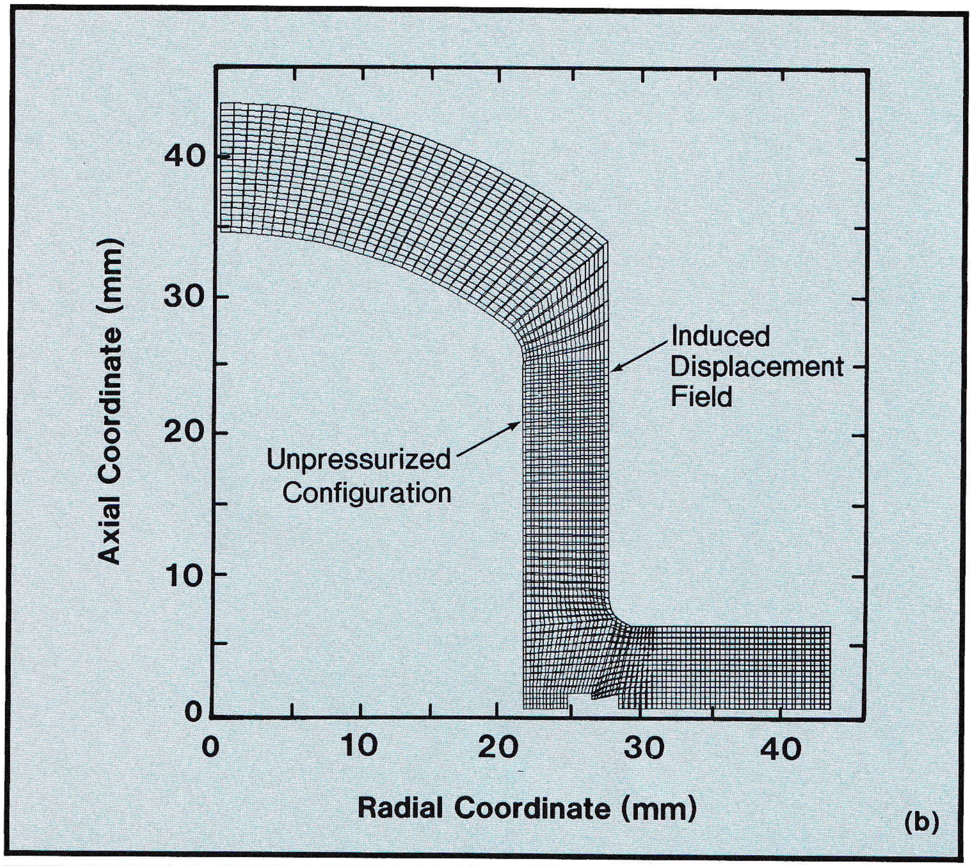
*A surrogate consisting of concentrated H_2SO_4 and water with UO_2 powder was used for the tests. The pressure generated by this surrogate exceeded the calculated pressure for all of the intended contents.



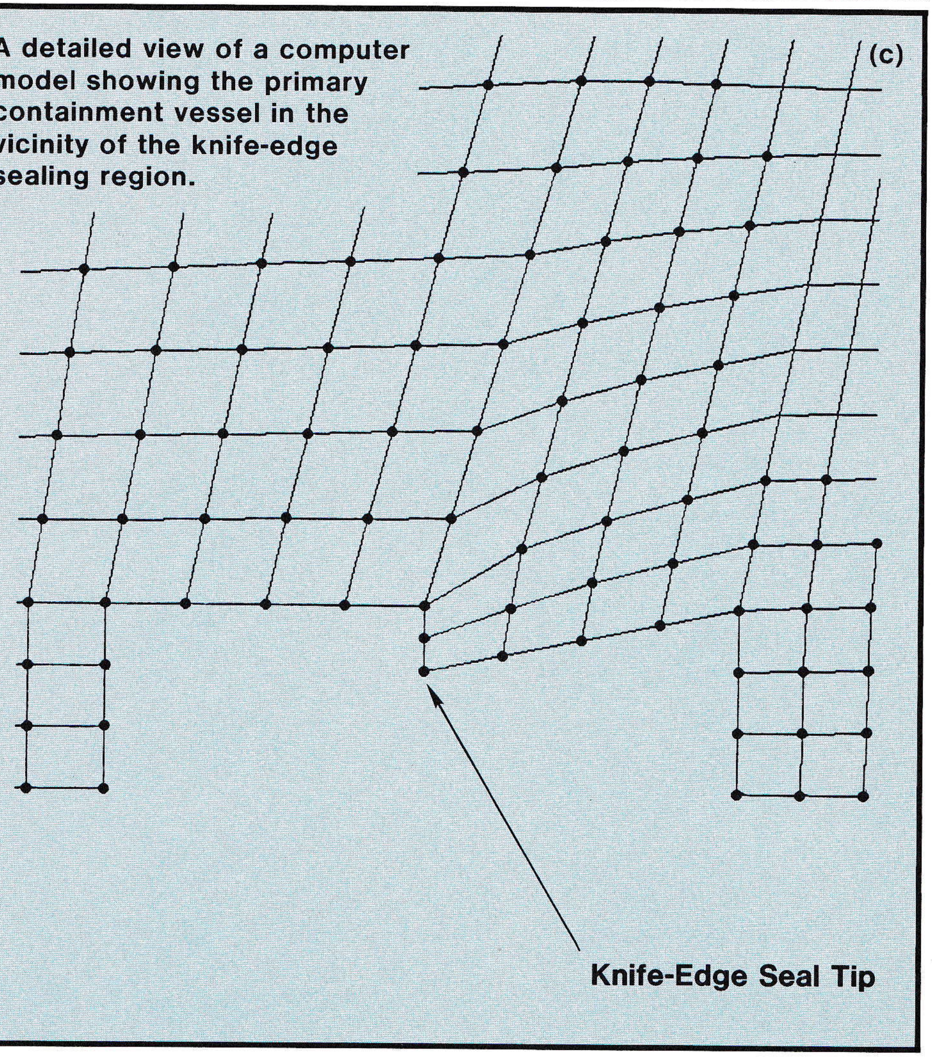
40
30
20
10
0
0
10
20
30
40
Axial Coordinate (mm)
Radial Coordinate (mm)
Induced Displacement Field
Unpressurized Configuration
(b)

Actual pressure- and temperature-induced displacement field superimposed on an unpressurized configuration at ambient temperature.

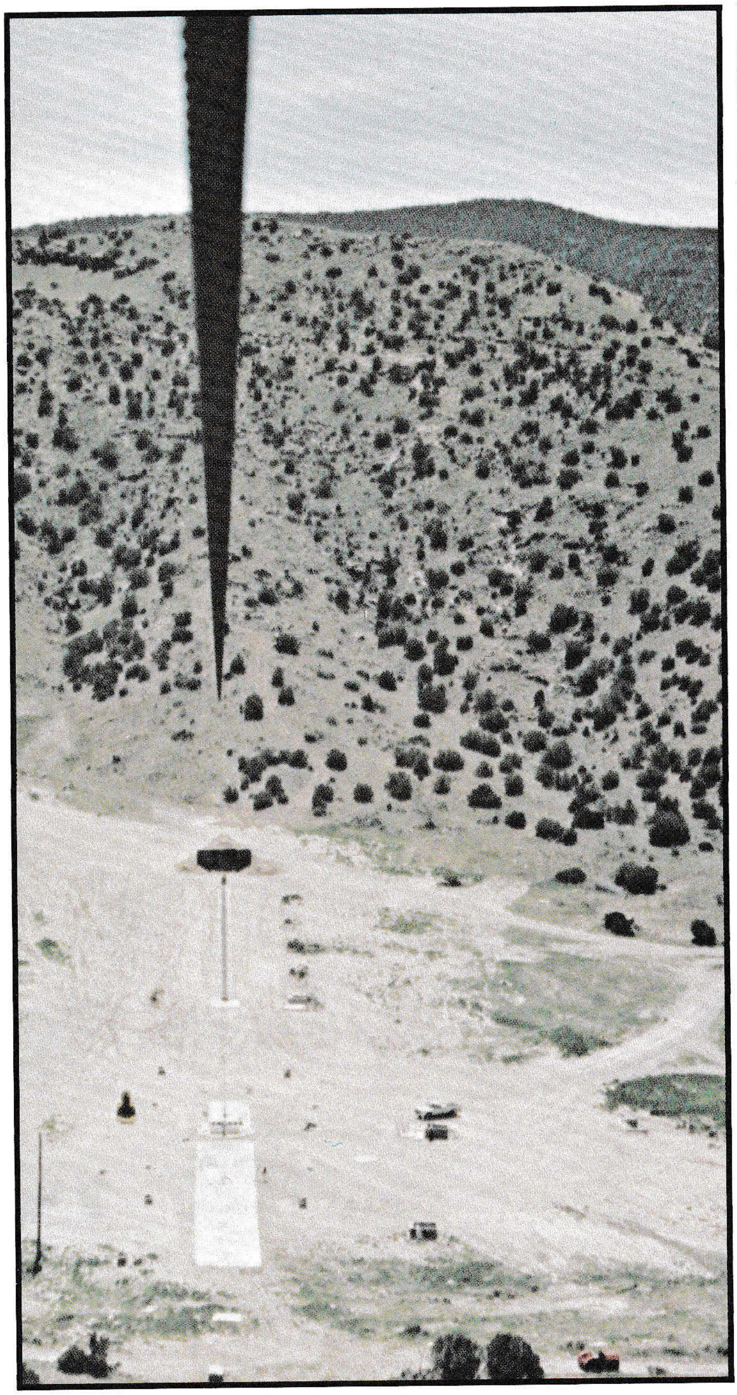
subjected it to a very substantial overtest at an external hydrostatic pressure of more than 34.5 MPa (an overload factor of 8.3) for longer than 8 hours in color-dyed water. There was no indication of dye or water inside the copper seal region after the test.

The secondary capsule fits very closely inside the containment vessel and provides the last protective layer for the radioactive contents. Stress analysis for this component involved: (1) measuring stresses in a thin, finite-length, closed cylinder clamped at both ends, (2) measuring stresses in a pressurized spherical cap clamped along its periphery, and (3) doing a thread-shear evaluation at the closure end. At 150% of the maximum normal operating pressure, the capsule exhibited a safety factor of 13.5. This large safety factor is a result of designing the capsule to withstand the much larger pressures that would result from accident environments.

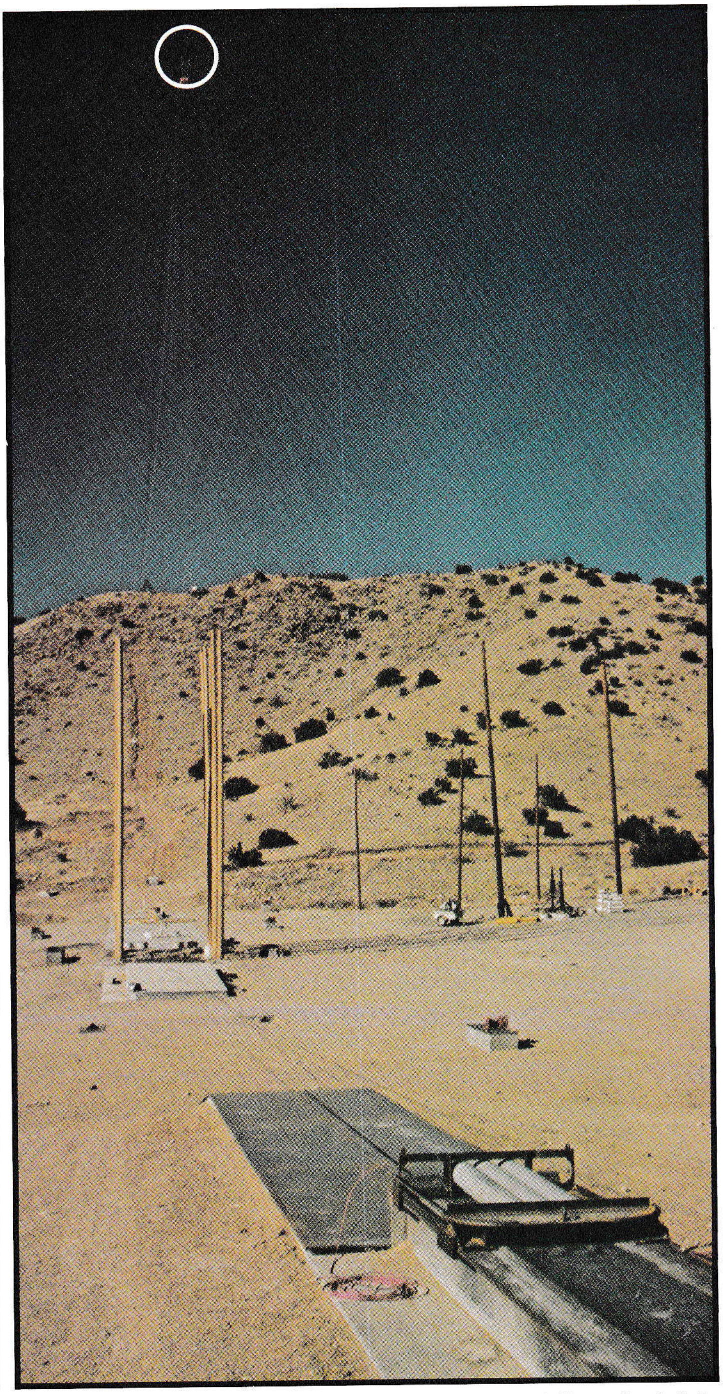
A detailed view of a computer model showing the primary containment vessel in the vicinity of the knife-edge sealing region.



(c)
Knife-Edge Seal Tip

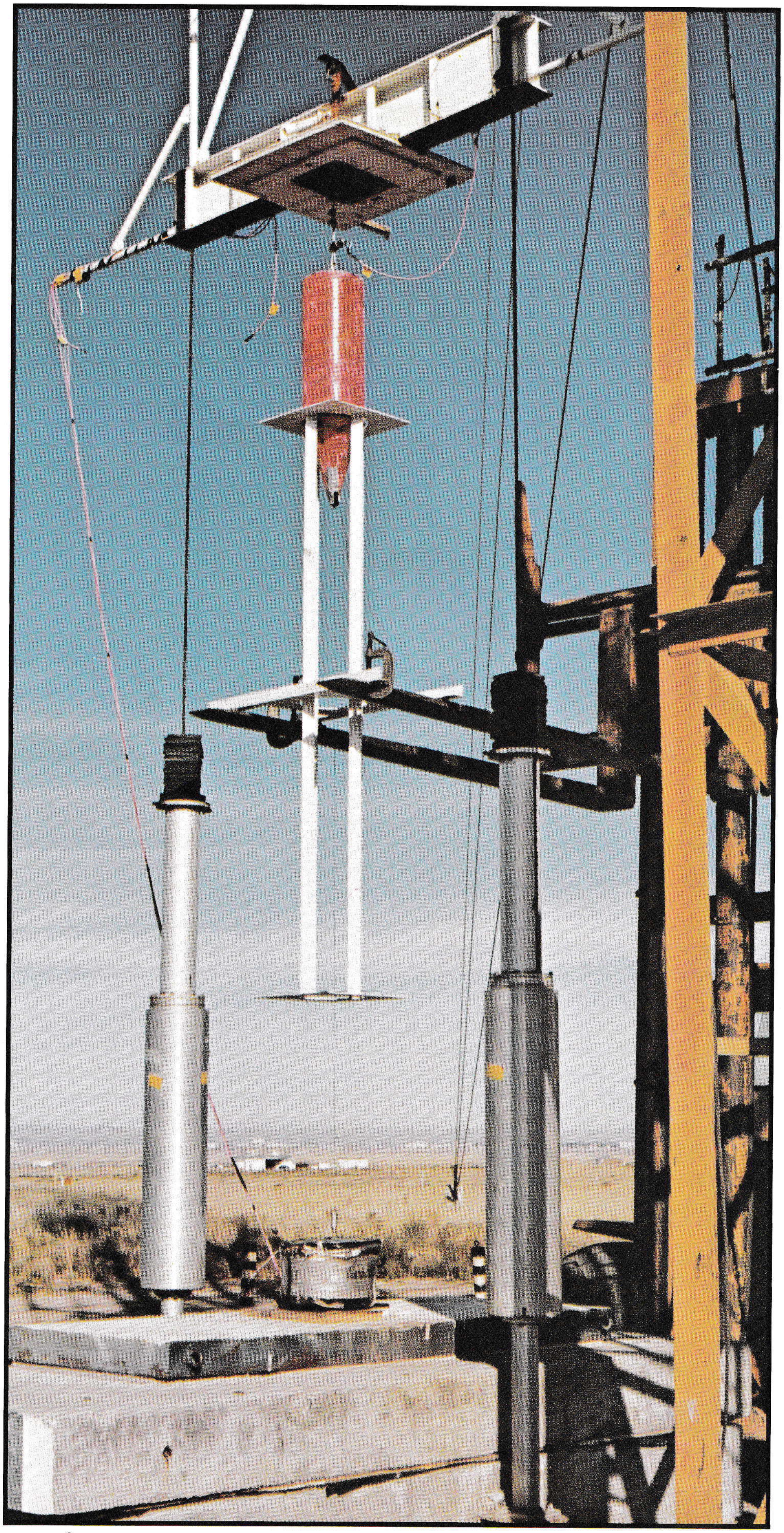


Looking down on the impact test pad (large white rectangle) and rocket sled track from a suspension cable mount of the Albuquerque pulldown test facility.



Test package (in white circle) is supported by the suspension cable. Pulldown cables are routed through pulleys and attached to the rocket sled in the foreground. The rocket sled provides a test package velocity of 130 m/s (422 ft/s) perpendicular to the unyielding surface. Additional cables assure that the package maintains a preselected orientation at impact.

A 230-kg (500-lb) steel spike is positioned 3 meters above a test package resting on an unyielding surface at our drop tower facility. The test package was crushed in a previous test and the steel spike is aligned to impact the crushed area.



We chose redwood and maple for their good charring properties. When a slash test opened the overpack in two places, allowing a chimney-like effect in a subsequent fuel fire test, the redwood charred and heated but retained its structure and kept the titanium load spreader and its contents in place. We selected titanium as the load spreader because it has a very high strength-to-weight ratio as well as high strength at elevated temperatures. The overpack, made from 304 stainless steel, was selected for its ductility and corrosion resistance. Comprehensive stress analyses were performed on the overpack, with emphasis on the riveted and welded handles used to tie down the packages during air transport.

The package was subjected to a series of tests that simulated accident conditions. These sequential overtests represented abnormal environments in the sense that such environments, especially in sequence, would be encountered only in an exceedingly small number of accidents.

Qualification and Acceptance Criteria

A summary of pertinent US and international test and acceptance requirements that had to be met before our package was certified by NRC for air transportation of plutonium.

Qualification Criteria

SEQUENTIAL TESTS

- Impact: 130 m/s (422 fps; 250 knots) perpendicular to a flat unyielding target.
- Crush: 310 kN (70,000 lb) through a 51 mm (2 in) wide steel bar.
- Puncture: 230 kg (500 lb) steel probe dropped 3 m (10 ft).
- Slash: 45 kg (100 lb) steel angle bar dropped 46 m (150 ft); twice onto the package tilted at 45°
- Fire: engulfed in large jet fuel fire of 1010°C (1850°F) for one hour; left to self-extinguish.
- Submersion: under 1 m (3 ft) of water for 8 hours.

INDIVIDUAL TESTS

- Hydrostatic: 4.1 MPa (600 psi) for 8 hours [equivalent to 411 m (1350 ft) depth].
- Free-Fall: impact test at terminal velocity (test required only if terminal velocity is > 250 knots).

Acceptance Criteria

CONTAINMENT OF PLUTONIUM

Release following test sequence must be less than 2.55×10^{-6} g of plutonium in one week.

No release from double containment (for sources > 20 Curies) following normal or accident conditions, measured as an air leak rate less than 10^{-7} cm^3/s.

SHIELDING

Normal transport requires that external radiation be limited to:

10 mrem/hr @ 1 m, and
200 mrem/hr @ container surface.

Post-Accident - external radiation must be limited to:

1 rem/hr @ 1 m.

CRITICALITY

Undamaged single packages and large arrays must be subcritical, and arrays of damaged packages must be subcritical following individual and sequential tests.

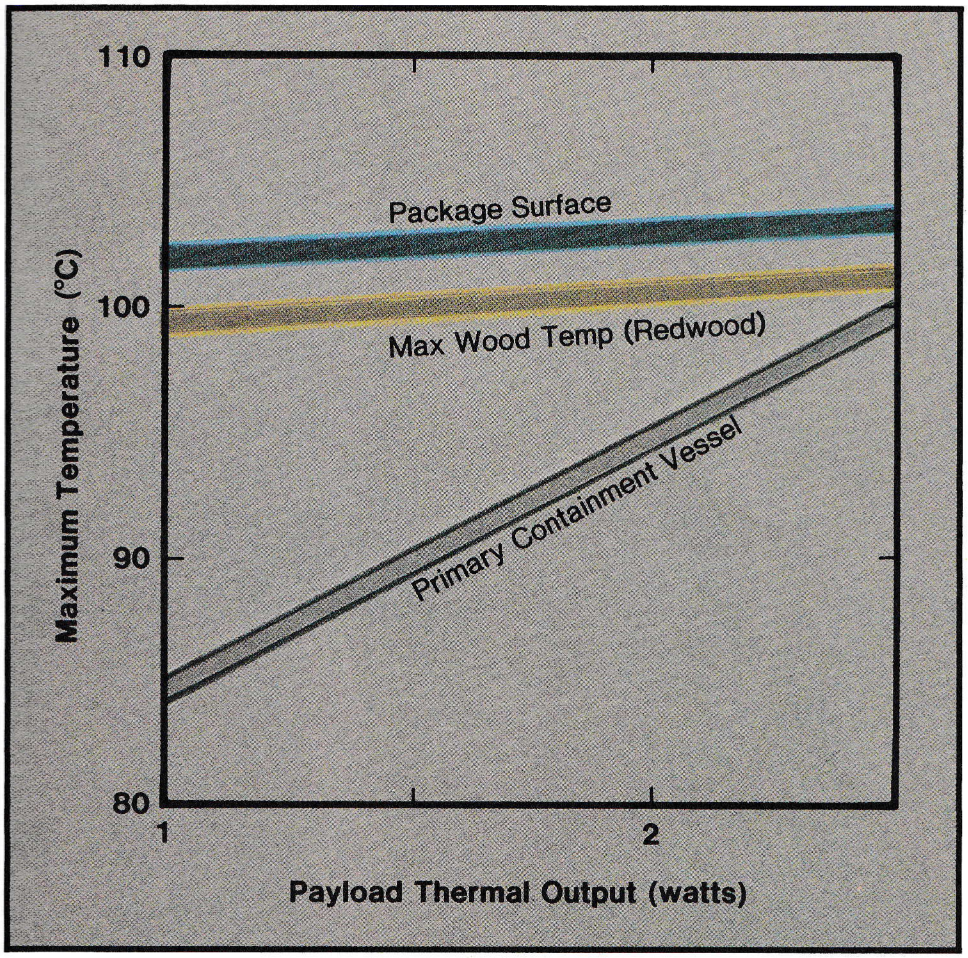
Thermal Evaluation

The maximum thermal load from a radionuclide source that could be accommodated in the vessel without exceeding acceptable operational temperatures for the package components and materials was determined using a finite-difference, heat-transfer method. In the analysis, we assumed an ambient temperature of 54°C and a high solar flux of 930 W/m^2 (295 Btu/hr-ft^2) impinging on the package for 16 hours per day followed by 8 hours of darkness. The package was modeled lying on its side, a worst case in respect to insolation. With other conservative features, such as no wind to enhance convective cooling, the model was run until a periodic steady-state temperature distribution was achieved. The results show that while the physical model of the package is axisymmetric, the temperature distribution throughout is not. We also analyzed other conditions, such as minimum temperature, to determine the range of internal pressures and thermal stresses.

An analytical model for a redwood-protected package was subjected to a blackbody radiation source of 1010°C to simulate a jet-fuel-fire environment. The model predicted a char depth of 53 mm in the outer redwood covering after about 30 minutes of fire exposure, with a char-front temperature of about 288°C, and a temperature ahead of the char-front of about 108°C. These results provided the basis for deciding the thickness of the protective layer of redwood. The package was subjected to the fuel fire test after having undergone all other tests specified as normal and accident conditions of transport. In all cases the package survived intact; the effects of all previous individual and sequential tests were negligible. At the conclusion of the fuel fire test the redwood and maple were charred, as expected. The outside shell of the overpack did not melt and it contained the load spreader, which retained the containment vessel and the maple char. Results of this severe fire test agreed with our overall predictions from the model.

Radioactive Material Containment

The primary and secondary radioactive material containments are designed to meet a very clearly stated requirement: the release from the primary containment vessel of no more than 2.55×10^{-6} g of plutonium in one week following the accident tests described. This quantity of plutonium is for a typical mixture of recycled plutonium-oxide



The maximum operational temperatures of selected surfaces of the package as a function of the radionuclide thermal output at any time during a 24-hour period after attaining periodic steady state. The period includes 16 hours of solar insolation followed by 8 hours of darkness.

powder. The release fraction is defined by International Atomic Energy Agency safety standards. Two methods were used to verify the containment capability of the vessel and capsule assemblies. The primary method was to measure helium leakage across their boundaries. The other was a direct measurement to determine whether any surrogate contents* (UO_2) had escaped during the performance tests (see page 36).

Radiation Shielding

To determine the radiation environment outside the package, we made calculations with various payloads of plutonium or mixed uranium/plutonium-bearing materials. Our isotopic mix of 47 g of highly recycled plutonium, which produces 2 watts of heat, provided a worst-case radiation source model.

Radiation transport computer calculations were performed on the package in normal and post-accident configurations to determine the radiation environments. A one-dimensional calculation for the bare vessel shows a total dose of 630 micro-sieverts/h (63 mrem/h) at its surface. Two different computer programs were used to calculate dose rates on the undamaged package surface and at 1 meter from the surface at the top and side. The results of the two programs showed close correlation, calculating 74 μSv/h at the surface for the one-dimensional program and 76 μSv/h for the two-dimensional program. Dose rates at 1 meter ranged from 2.3 to 3.1 μSv/h. Post-accident dose rates were calculated using a three-dimensional program which showed that worst-case top and side dose rates differ (3.3 and 4.0 μSv/h, respectively) since the minimum distance between the source and the package exterior is modified by the damage.

Even with a worst-case radiation source, all dose rates were within regulatory criteria. With a typical payload of 8 g of plutonium, the dose rates are dramatically decreased; for instance, 107 instead of 630 μSv/h at the bare surface.

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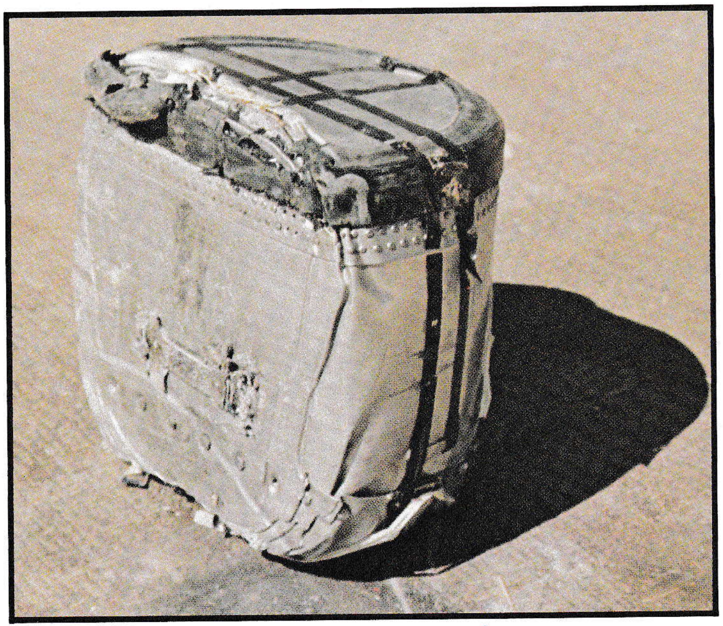
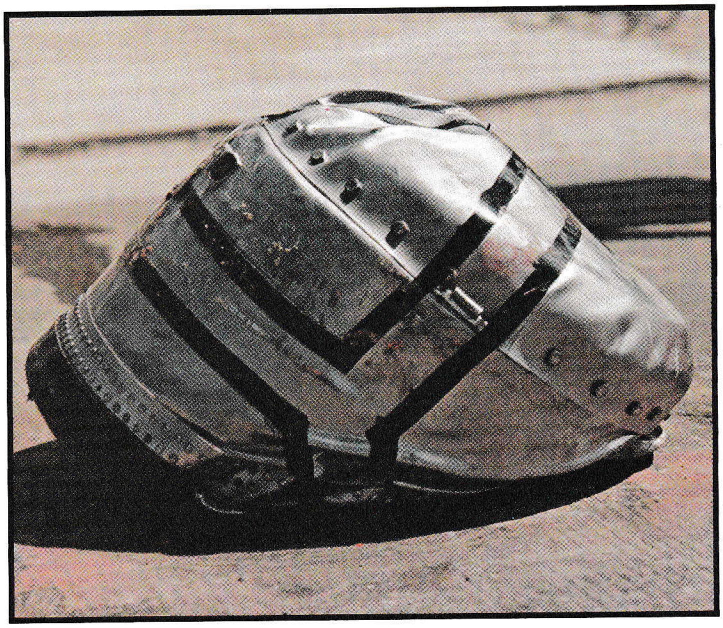
*Depleted sinterable uranium oxide (UO_2) powder was used as a surrogate for plutonium oxide (PuO_2) powder during container testing. This material replicates the aerosol characteristics of PuO_2, is not very hazardous, and can be detected in quantities as low as 10^{-8}g.

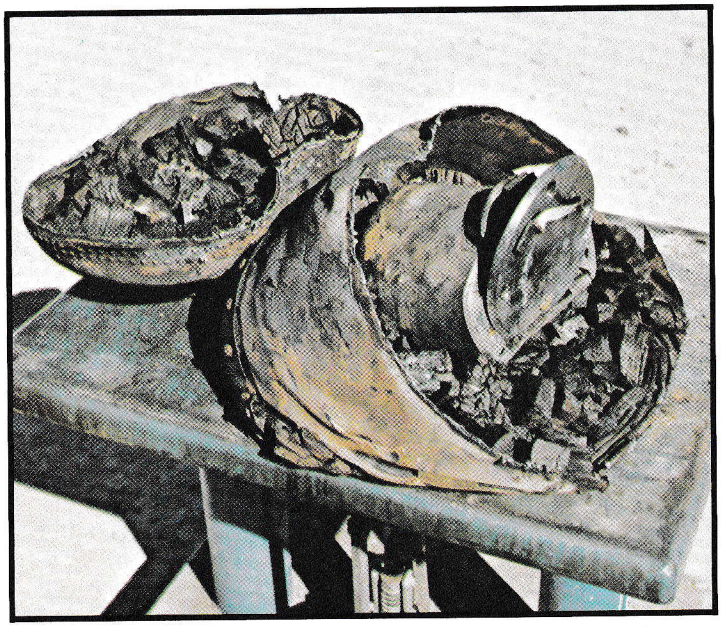


The rocket pulldown facility was used to test six different package orientations. The package was turned 90 degrees about 2 perpendicular axes between successive tests. Each primary containment vessel was loaded with helium and surrogate radioisotopic sources to determine whether leakage occurred.

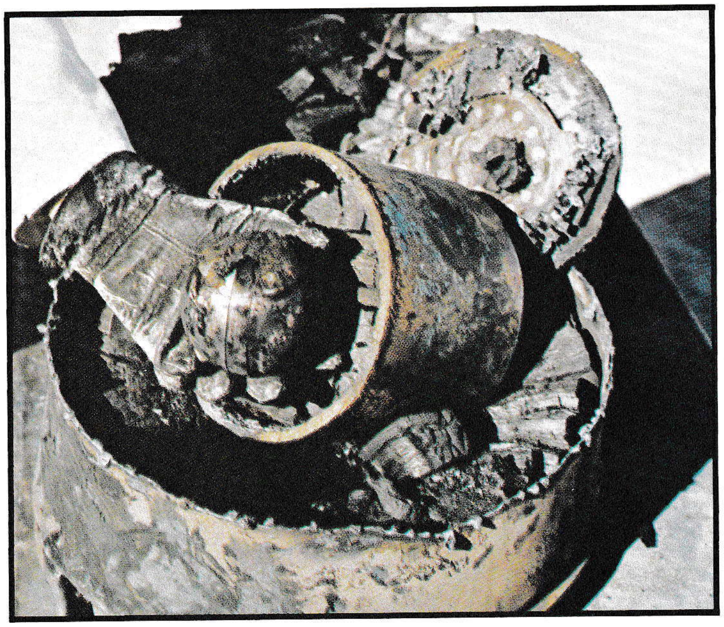


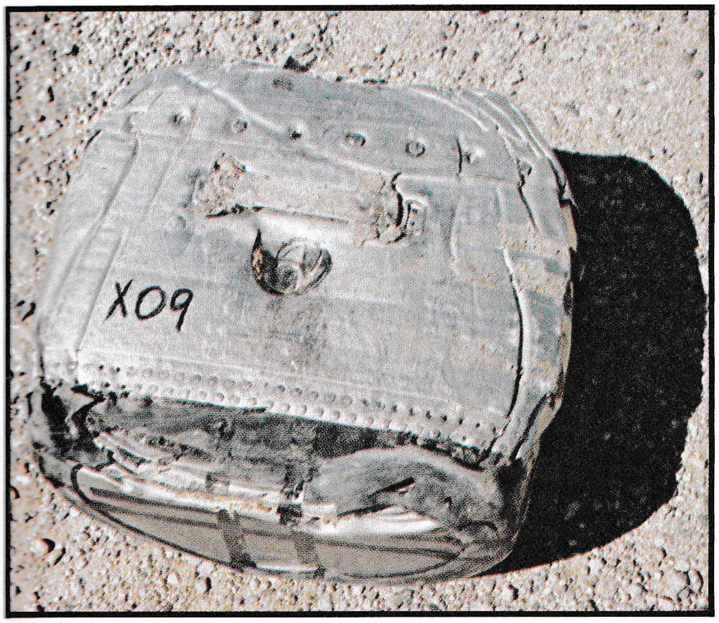
Typical impact damage to the package. Impact velocities were about 130 m/s onto an unyielding surface. This velocity is in excess of any possible aerodynamic trajectory velocity in the atmosphere or upon impact, and satisfies the free-fall test requirement.

Using an enhanced draft on a jet-fuel fire in a large-diameter pool, the package was exposed to luminous flames at 1010°C for 60 minutes. This caused severe burning and charring of the redwood and exposed the titanium load spreader. Penetrations in the outer stainless-steel skin from the earlier slash test had produced a chimney-like effect that allowed heat circulation during the fire test. However, the ceramic-felt insulation and maple wood within the load spreader limited thermal exposure of the primary containment vessel.

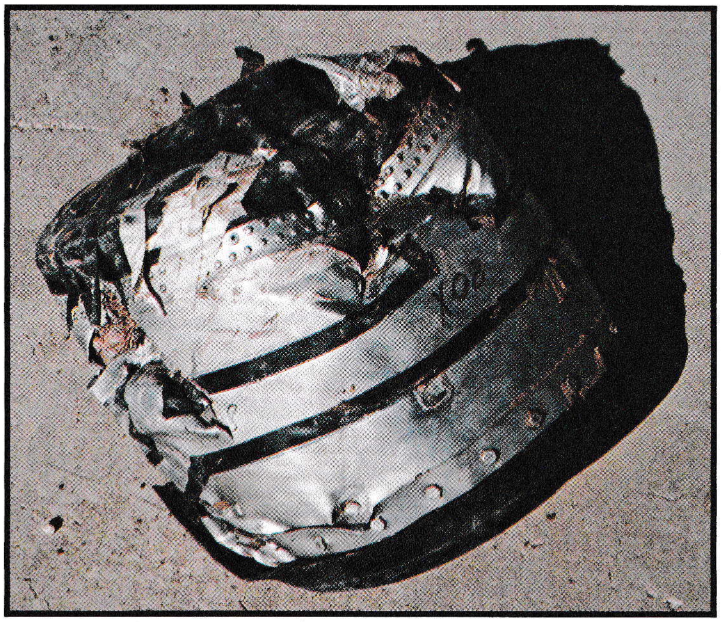


Post-test disassembly of a damaged package after submersion under one meter of water for 8 hours. After cleaning, the vessel looked new and was intact, leaktight, and structurally sound. No nuclear material had escaped.



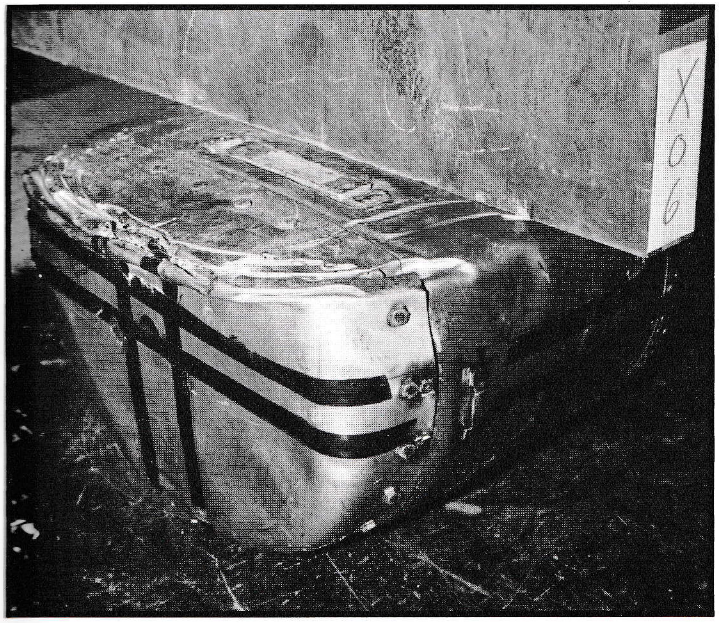


The crushed package after impact and penetration by a 230-kg solid steel probe dropped from a height of 3 meters.

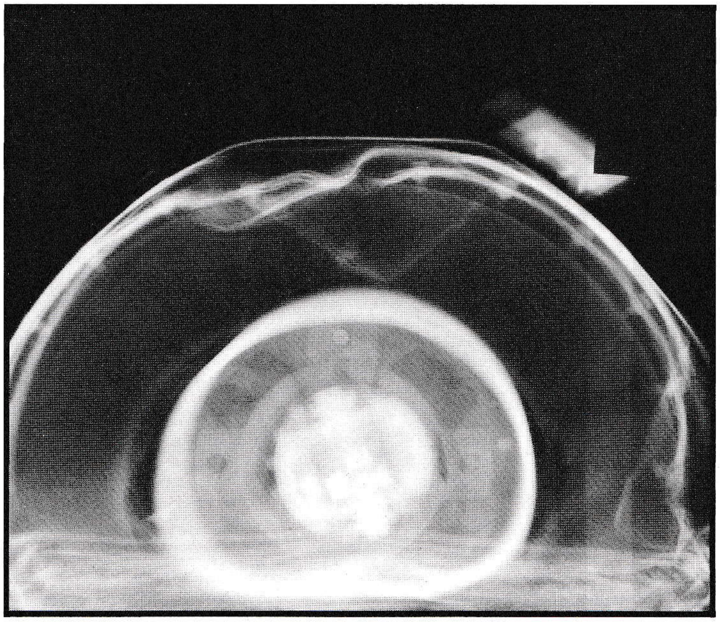


Slashes in package were made by an angle steel section, 2 m long, weighing 45 kg, and guided to prevent tumbling. It was dropped from 46 meters onto the test unit. Two drops were made on each package to produce two cuts at a 90° angle from each other; the structural steel members struck the side of the package at 45 degrees with the package supported on an unyielding surface. The angle steel penetrated generally to a depth of 100 mm. It did not reach the titanium load spreader.

The damaged package is subjected to a static compressive load of 311 kN applied with a solid steel beam in the orientation expected to result in maximum damage (based on radiographs of previous tests).



A radiograph showing the primary containment vessel embedded in the damaged package.



Package Containment — Post-Test Results

Component	Test Condition	Requirement (Regulatory Acceptance Standard)	Results		
			Helium Leak Rate (cm^3/s)	Uranium Detection Measurement	Containment Achieved
Primary Containment Vessel	Normal conditions of transport (Appendix A of 10 CFR 71)[a]	No release	$<1 \times 10^{-10}$	No release[b]	No release
	Hypothetical accident conditions (Appendix B of 10 CFR 71)[a]	No release	$<1 \times 10^{-10}$	No release[b]	No release
	NUREG-0360[a] criteria	A2/week[c]	$<2 \times 10^{-5}$	No release[b]	$<A2 \times 10^{-5}$[d]
Secondary Containment Capsule	Normal conditions of transport (Appendix A of 10 CFR 71)[a]	No release	$<2 \times 10^{-9}$	No release[b]	No release
	Hypothetical accident conditions (Appendix B of 10 CFR 71)[a]	No release	$<2 \times 10^{-9}$	No release[b]	No release

[a] NRC regulations.

[b] No release above detection capability of 10^{-8} gram.

[c] For a typical mixture of recycled plutonium-oxide powder, an A2 quantity is approximately 2.55 mg of plutonium.

[d] Calculated value; no actual release.

Containment Exceeds Requirements

Extensive analysis and testing during design and development resulted in a package that provides an extraordinarily protective enclosure for the safe air transport of radioactive samples.

Plutonium containment was confirmed to be orders of magnitude better than international requirements. After exposure to all design and test criteria, the package showed no detectable radioisotopic release. Further, criticality analysis shows that infinite arrays of damaged packages, with the most fissionable contents allowable, remain subcritical.

The accident environment tests of our small, air-transportable package were carried out at our Albuquerque facilities and witnessed by a team of international observers. Licensing for the package has been approved by the Nuclear Regulatory Commission and the Department of Transportation, which allows its use by member nations of the *Treaty On The Non-Proliferation Of Nuclear Weapons.*

For additional information, contact John A. Andersen, (505)844-6121.

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Our plutonium air-transportable package passed a battery of extraordinary tests. See page 24.

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